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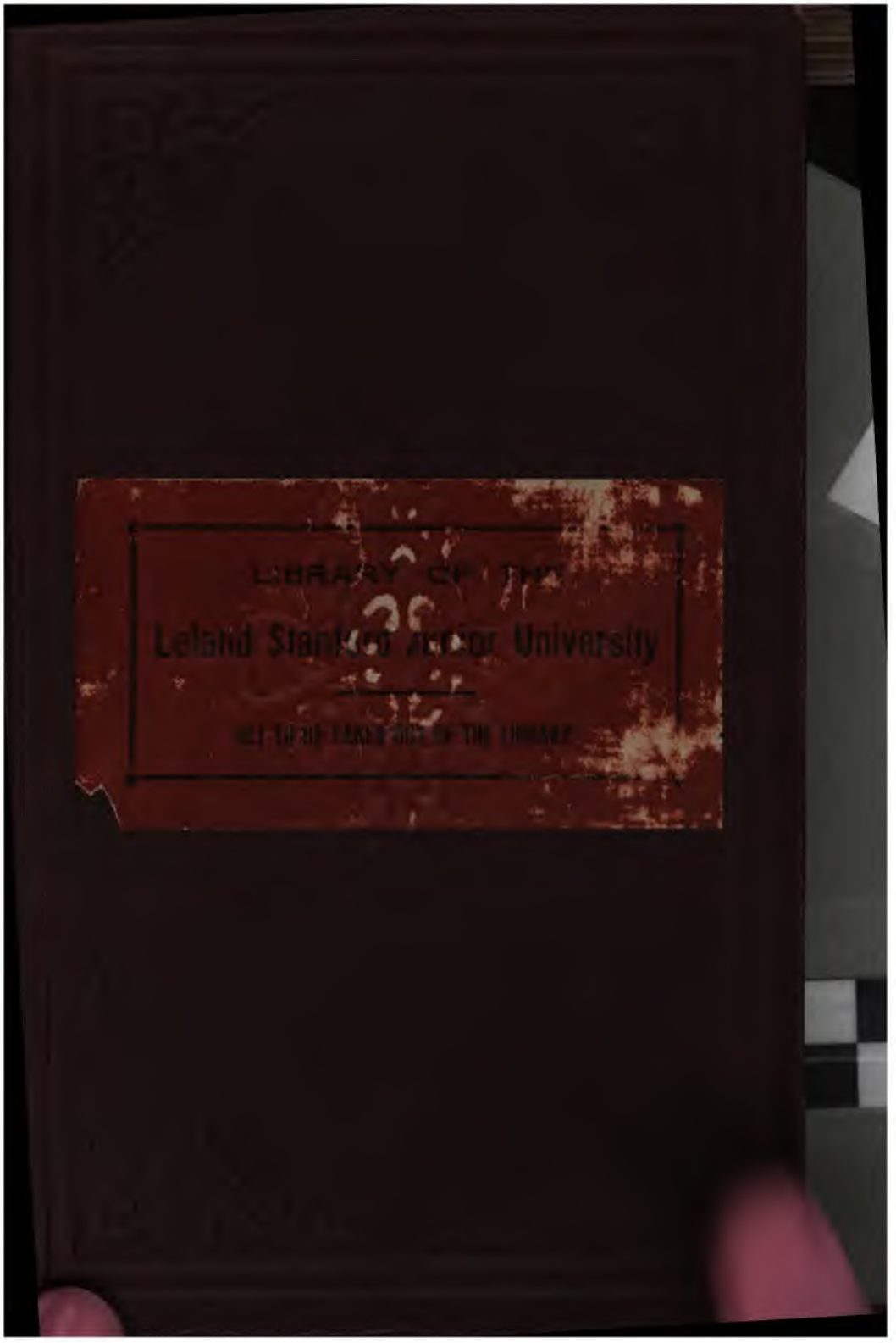
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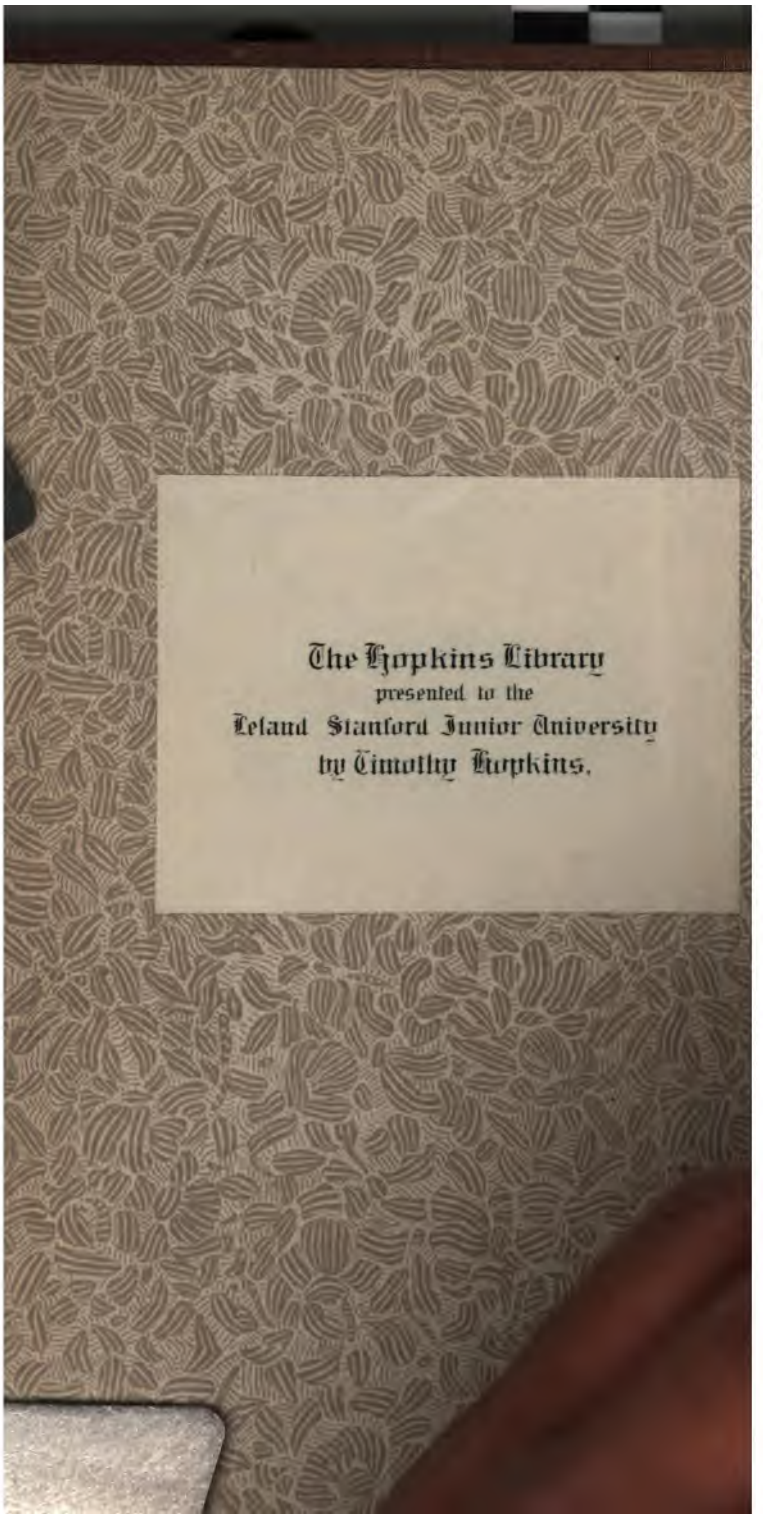
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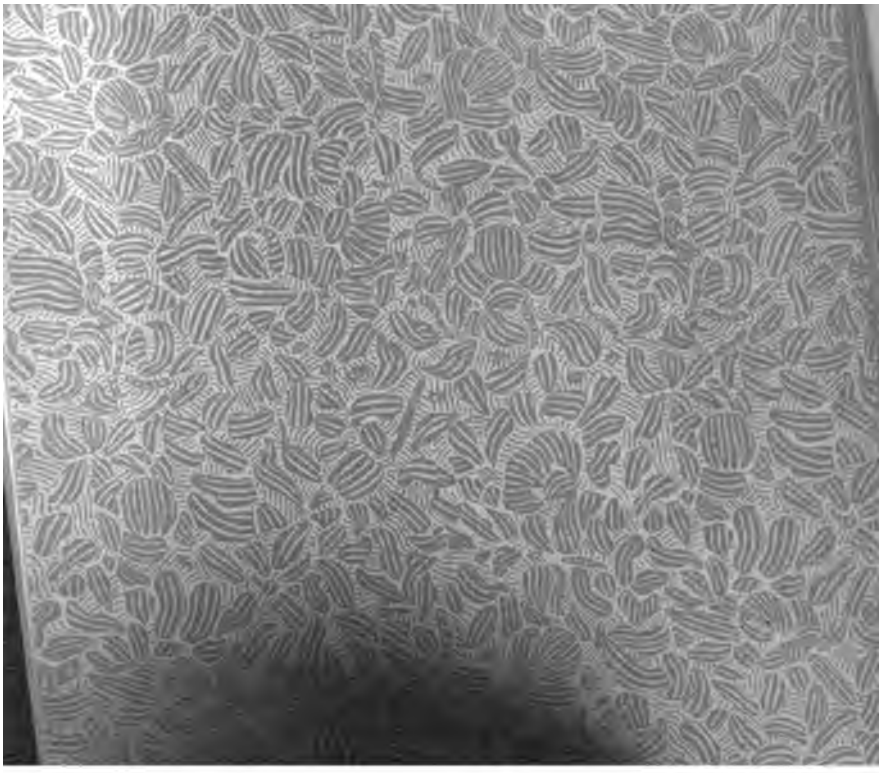

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DEDICATED TO

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OF PHILADELPHIA, PA.,

(Publisher,)

THE FRIEND, ADVOCATE, AND CHAMPION

OF

THE AMERICAN WORKMAN.

PREFACE.

THE following pages have been compiled at the
est solicitation of a number of correspondents re
in different sections of the country, who have re
previous works of the writer's on steam engine
evidently with both interest and profit. Many
asked: "Why not get up a book on the locom
and complete the series?" and this book is the
of those suggestions. There necessarily comes a
in the life of every locomotive engineer, partic
when old age and its attendant infirmities beg
make themselves felt, that he fain would resig
throttle valve, and leave the foot-board to yo
and stronger men.

To do this and find employment suited to his
and experience, he turns, naturally, to the shops.
prepare himself for a responsible position, with
ary at least equal to that received while running
road, he should devote his leisure hours to stu
observation of each and every advance made i
construction of locomotives; and by every
means come-at-able to keep himself "posted,"
abreast of the times. The means of so doin
within the reach of every man who desires to im
himself. Good books and newspapers on steam
gineering abound, and can be had for a mere

compared with their value. Every engineer should have a library—every live, intelligent, progressive one has one—and that library can be filled with valuable books and papers without their owner denying himself any of the necessaries of life. Colburn, Norris, Forney, Roper, Reynolds, Hoxie, Smith, and other eminent men have given their time and talents "to make the rough way smooth" for their less fortunate fellow-craftsmen, and be it said to their credit, they have not lived nor labored in vain.

To those worthy seekers after "more light," who, after perusing these pages, wish to continue their studies, he would recommend, in addition to the works of the engineers above mentioned, for a *theory* of the steam engine, "A Text Book on the Steam Engine," by T. M. Goodeve; and for a *history* of the steam engine from the time of Hero, 200 B. C., to the present day, "The Growth of the Steam Engine," by Prof. R. H. Thurston. As regards newspapers, "*The American Machinist*," "*The Mechanical Engineer*," and the *Scientific American Supplement*," are worthy of all praise and support.

In conclusion, the writer will add that he claims no *originality* for this work; *original* books on this subject are scarce and hard to find; it is, on the contrary, a compilation of valuable papers on locomotive engineering, by some of the most advanced, most talented, and most scientific engineers that the country has yet produced, *and hence all the more valuable*.

It requires no argument to prove that [illegible]ined

ideas, skill and experience of such eminent men in the profession as Frank C. Smith, Lewis F. Lyne, Chas. A. Hague, Wm. H. Hoffman, W. Barnet Le Van, Wm. J. Williams, Melville Clemens, John W. Hill, F. B. Allen, Angus Sinclair, and others, are of far more value than that of any one man, be his skill and experience what it may, and the writer is indebted to them and the newspapers mentioned, and particularly "*The American Machinist*," for the valuable information found in these pages.

Should the perusal of this volume assist one worthy man or boy to better his condition in life, the only object of the writer will be fully accomplished.

EMORY EDWARDS.

Baltimore, Md.
309 Carrollton Avenue,
(Lafayette Square),
August 10, 1883.

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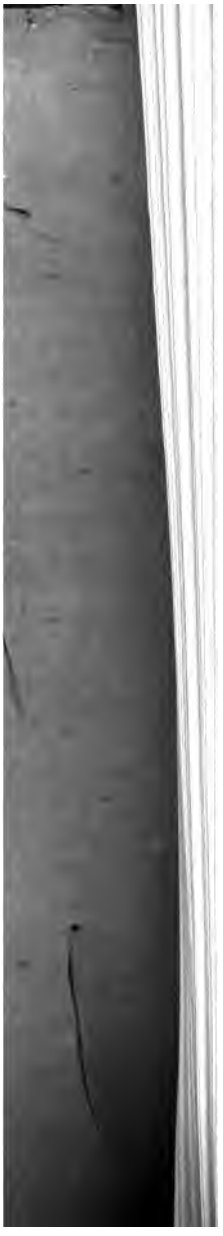

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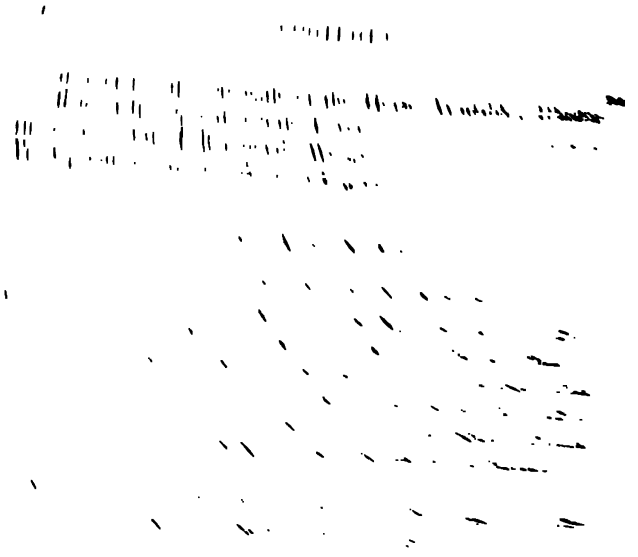

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INTRODUCTION.

STEAM.

THE most prominent of the properties possessed b steam are its high expansive force, its property of co densation by an abstraction of its temperature, its co cealed or undeveloped heat, and the inverted ratio o its pressure to the space which it occupies. Steam the result of a combination of water with a certai amount of heat; and the expansive force of stea arises from the absence of cohesion between an among the particles of water. Heat universally ex pands all matter within its influence, whether solid o fluid; but in a solid body it has the cohesion of th particles to overcome, and this so circumscribes it effects that in cast-iron, for instance, a rate of tempe ature above the freezing point sufficient to melt i causes an extension of only about one-eighth of a inch in a foot. With water, however, a temperatur of 212°, or 180° above the freezing point, and whic is far from red-heat, converts it into steam of 170 times its original bulk or volume.

All bodies may exist in either one or all of thre different states, namely, the solid state, the liquid stat and the aeriform state, or state of vapor. Water, fo

example, may exist as ice, liquid, and steam; and the condition which it assumes depends on its pervading temperature. Steam cannot mix with air while its pressure exceeds that of the atmosphere, and it is this property, with that which makes the condition of a body dependent on its temperature, that explains the condensing property of steam. In a cylinder once filled with steam of a pressure of 15 pounds or more to the square inch, all air is excluded. Now, as the existence of the steam depends on its temperature, by abstracting that temperature, which may be done by immersing the cylinder in cold water or cold air, the contained steam assumes the state due to the reduced temperature, and this state will be water. And, as the water cannot occupy the volume which it did under its former temperature, it follows that its reduction in volume must remain a vacuum. A cylinder, therefore, filled with hot steam, may be condensed by an abstraction of its heat, and a vacuum will be produced in the cylinder, with a few drops of water at the bottom, which may be pumped out by an air-tight pump, leaving the vacuum perfect. When this principle is employed in removing the atmospheric pressure opposed to the back of a piston in a steam engine, such an engine is termed a condensing engine: and in such engines more work may be done with the same pressure of steam than by a non-condensing engine, as the absence of the weight of the air on the negative pressure on the back of the piston is equivalent to a positive pressure on the other side, and contributes by so

weight of the water contained by the latter to be 6¾ lbs. Now this addition of one pound to its weight has resulted solely from the admission of steam to it, and this pound of steam, therefore, retaining its own temperature of 212°, has raised 5¾ lbs. of water 180°, or an equivalent of 990°; and including its own temperature, we have 1202°, which it must have possessed at first. The sum of the latent and sensible heat of steam is in all cases nearly constant, and does not vary much from 1200°. It is from this property of steam that it becomes of such essential service in heating buildings; one square foot of superficial surface of cast-iron steam pipe will keep 200 cubic feet of air at a genial summer heat; but a square foot of the surface of a bar of iron, of the same perceivable temperature, would scarcely start the frost on the windows on a cold morning. If a known volume of steam of a certain pressure be made to occupy but one-half that volume, its elastic force will be doubled; or, in other words, the same pressure is exerted within one-half the original capacity. By pressure we mean the initial elastic force of the steam, which is always the same in equal weights of steam, and which can only act with greater intensity of pressure by restricting the area exposed to its action. In fact, it is an established law of steam, and of all elastic fluids generally, that the pressure which they exert is inversely as the space occupied; or, to be more precise, it is very nearly so. The elasticity of steam increases with an increase in the temperature applied, but not in the same ratio. If steam is gen-

erating from water at a temperature which gives it the same pressure as the atmosphere, an additional temperature of 38° will give it the pressure of two atmospheres; a still further addition of 42° gives it the tension of four atmospheres; and with each successive addition of temperature, of between 40° and 50°, the pressure becomes doubled. It is well for the student of the steam engine to know the reason of this effect, and we will endeavor to explain it. We have already said that there is no cohesion among the particles of fluids, but there is, however, an attraction between all matter in nature. The action of heat in generating steam has to overcome this attraction among the particles of the water, and likewise the gravity of the water itself. As the water becomes rarefied by heat, and, either in its natural state or as steam, occupies a greater volume, this attraction is diminished, and also the weight or gravity of the water; hence an additional rate of temperature does not have to contend with the same resistance as the temperature which preceded it, and is, therefore, enabled to produce greater effects in the generation of steam. Among a variety of facts and notes relative to the nature of steam, we select the following: If water be boiled in an open vessel, no temperature greater than that for the boiling point, which for fresh water is 212°, can be produced in it. All surplus heat which may be applied passes off in the steam. If the vessel be closed, and the steam as it is formed be retained within it, the temperature may be raised, and retained in the steam. If the steam, as

temperature; and so at any other temperature. If t
natural pressure on the surface of the water be
moved without a corresponding reduction in the t
perature, a violent ebullition at the water-level is
immediate result. Thus, suppose the entire ste
room in a boiler to be six cubic feet, and the conte
of the cylinder which it supplies to be two cubic f
at each stroke of the piston one-third of all the st
in the boiler is discharged, and the surface of
water is consequently relieved from one-third of
pressure upon it before that stroke. The temperat
remains the same, but as it does not bear the natu
relation to this diminished pressure, it causes
water to boil violently, and produces foaming. Fo
ing is the cause of which priming, or working w
along with the steam into the cylinders, is the ef
Provision must therefore be made in all boilers, t
they may have a large extent of steam-room c
pared with the cylinders which they supply. Anot
result attending the formation of steam is, that w
an engine is in operation and working off a pro
supply of steam, the water-level in the boiler a
cially rises, and shows by the gauge-cocks a sup
greater than that which really exists. This is ow
to the steam forming in the water and rising
bubbles to the surface, and displacing by its bulk
amount of water indicated by the rise at the gau
cocks. As the production of steam under the s
temperature cannot continue under an increased pr
ure, it follows that when the discharge of steam

stopped, and its entire pressure is thrown on the surface of the water, steam is no longer generated, and the water takes its natural level. At whatever point in a boiler steam be taken, there is a determination of water to that point, which is occasioned by the sudden reduction in the pressure, owing to the withdrawal of the steam. This is the case with all boilers having steam domes with throttle in the same; and it was for this reason that, on certain new engines lately constructed, the steam-dome was omitted, and in its stead a steampipe, perforated on its upper side, was extended the whole length of the boiler, occupying the position usually given to the steam-pipe in ordinary locomotives. The object of this was to take the steam alike from all parts of the steam-room of the boiler, so that no rise of water should result at any one point.

CHAPTER I.

STEAM ENGINEERING.

THE observation and experience of the writer* have confirmed him in the opinion that there exists among so-called "practical men," a great need of "scientific education" on subjects directly pertaining to the business they may be engaged in.

The very foundation of science is the faculty of *calling things by their right names;* for by such a method only, can one be perfectly understood and answered accordingly.

These lines are written in the exacting light of Webster's dictionary, and it is suggested to all who may read them with the view of knowing just what they mean, to read with a dictionary close at hand, and if its occasional use will *start* readers in a habit of thoroughly comprehending whatever they give their attention to, an important step towards a scientific education will have been taken.

Science is simply "a positive statement of truth, established by observation and experiments," and can as well be applied to the operations of every-day work, as to the most intricate branches of human inquiry; in other words, there is one *best way* to perform every

* Hague.

operation in the different trades, varying, of course, with surrounding circumstances; and a comprehension of these best ways constitutes the science of the trade.

Art, on the other hand, is "the power of performing certain actions;" so it would seem then, for a man to be successful at his calling, he must acquire both science and art, or the knowledge of "how to do a thing," and the skill to "do it."

Some of the deductions in this chapter are based upon the theory of the "Mechanical Equivalent" of heat; a theory that has probably been established as firmly as any natural law, although some controversy was indulged in but a short time ago.

According to the above theory, heat is simply "a mode of motion," that is, an influence by which motion is produced among the atoms of substances; this *motion*, however, is imperceptible, the *heat* only being detected by the sense of feeling.

A comprehensive idea of heat would be, that it is a means employed by a *natural force* to produce motion; *why* the force should operate in the manner in which it does, is beyond the bounds of the present writing; indeed the "physical constitution of heat" is one of the mysteries not yet solved by science.

When a piece of iron is heated, then (scientifically speaking) the minute atoms of which it is composed are set in motion to a degree corresponding to the intensity of the force influencing them. If the motion is sufficiently increased, the iron passes from solid to liquid, or melts. The motion may be still further

increased until the substance of the iron combines with the oxygen of the air, combustion takes place, the heat is set free, the iron is destroyed, and there remain gases and cinders.

For convenience of comparison and measurement heat is divided into "units," in the same manner that distance is divided into inches.

Careful experiments by different men and at different times, have resulted in a standard of value for each unit of heat; this standard is "772 foot pounds," that is, the dynamic energy inherent in one unit of heat is equivalent to the dynamic energy required to lift 772 pounds one foot high, or one pound 772 feet high, friction not considered; this amount of work is considered to be the "mechanical equivalent" of one unit of heat.

Before proceeding further, a few definitions will be in order:

Force: Is any action that can be measured by weight alone.

Dynamics: Is a positive statement of truth, established by observation and experiment, in relation to forces in motion.

Dynamic energy: Is the mechanical power or work produced by forces in motion.

And now we come directly to our subject:

Steam engineering is a branch of the science and art of *developing dynamic energy from heat.*

The subject might be divided into several distinct branches, but the extent of this chapter is necessarily limited to a general treatment.

Heat having been produced by combustion of fuel, the first step is to provide some means for conveying it (heat) to where it can be placed under conditions favorable to the development of dynamic energy, or power.

The means employed in this case is water, and the instrument by which the power is made available for practical use is the Steam Engine; in these lines the well-known reciprocating engine, only, will be considered.

Water having absorbed heat, assumes the gaseous form, or becomes steam, and in this state acts as the vehicle by which the heat is transported from boiler to engine; but it must be borne in mind that it is not the steam but *heat* that does the work.

Before proceeding further, it will be well to observe that "dry saturated steam," is steam in which just sufficient heat has been absorbed to evaporate all moisture; its temperature and density (quantity of water) are elements which bear a proportion to each other, corresponding to the pressure.

When an excess of heat has been absorbed, the steam is said to be "superheated," and when a deficiency of heat exists, the steam is termed "wet."

Steam parts with heat, to be converted into effect by the operation of EXPANSION; for if it (steam) were confined in a tight vessel and perfectly protected from loss of heat by radiation, and not allowed to expand, it would possess no other forces than that of its pressure on sides of vessel, and its weight; its weight

would of course be the weight of the water which, having absorbed heat, became steam.

Without regard to loss by friction, radiation, and conduction, the utmost quantity of steam that could be consumed in the production of a certain power, would be when no expansion took place within the cylinder of the engine; in which case the steam would exert only its "force of displacement."

For example: The pressure in boiler is 100 lbs. per inch: induction valves of engine are "set" to admit steam during the whole stroke of piston; then steam will flow into the cylinder in a manner similar to that of water entering a pump; that is, the heat being supplied by fire under the boiler as fast as it passes into the cylinder in the form of steam.

In the above case the heat exerts only its *external* force, or that action measurable by weight alone; and it does so because heat generated in the furnace or boiler, having free communication with the cylinder through the medium of the steam, maintains the full pressure of 100 lbs. per inch throughout, and thus prevents expansion. The force of heat operating in this manner is similar to the force of so much weight acting through space.

An engine under such circumstances would be practically "pumping" the heat from the boiler, without utilizing any of its (heat's) mechanical equivalent.

On the other hand, an extreme towards economy in the use of steam would be, to admit the steam to the cylinder at the boiler pressure and then close the in-

duction valve at a point in the stroke that would cause the steam to expand in a non-condensing engine just down to the pressure of the atmosphere, and in a condensing engine down to the pressure due to the vacuum on exhaust side of piston.

Theoretically, and without regard to certain *counteracting effects* that will be discussed further on, the greater the difference between the pressure at the point of cut-off, and the pressure at the end of the stroke. the greater will be the quantity of heat converted into dynamic energy.

It is the province of the steam engineer to take into consideration the action of *all* natural laws pertaining to his vocation, and arrange his ideas in such a manner that his theory of construction will be adjusted to meet the demands of *every* influence that is exerted during the operation of producing HEAT, and converting its forces into mechanical effect.

The average economic results of the best modern practice are probably not far from 20 per cent. of total "heat value" of fuel; the average of ordinary performance, however, is far short of the above, and some specimens of the engineer's art in daily operation are doubtless so far in the rear, that they are very expensive property to own.

However well designed and constructed a steam engine may be, the full advantage of its merits cannot be realized unless the boiler is of a character and capacity to correspond. There are some boilers made in con- that render them capable of gen-

erating dry saturated steam, and in some cases superheated steam, but even with such boilers there is a very considerable waste of heat by radiation, absorption, etc.; there is also a comparatively large percentage of the heat of combustion, it will be observed, escapes up the chimney, for the reason that boilers giving off dry or superheated steam are so constructed, that some of the parts forming heating surface come in contact with steam, and of course the heat from the furnace must be considerably higher than that of contained steam, and continue so all the way to uptake, where the remaining heat enters the chimney and is lost; and so it would seem that with the present methods of generating steam, even in the best practice, a large proportion of the heat produced is not utilized: in other words, before the water is evaporated and steam is ready to enter the pipe for conveyance to the engine, the heat value of the fire is practically very materially reduced.

There is also a class of boilers, and doubtless the largest class in daily use, that are so arranged and operated that it is impossible to obtain dry steam from them; the heating surface is badly distributed, and, as a consequence, very little steam is generated at some points, while at others the water absorbs heat so rapidly that the resulting steam, in endeavoring to escape to the surface of the water, finds such crooked or narrow passages, that in forcing its way through them a portion of the water is carried along, and the result is, the steam never gets rid of the water with which it

(steam) becomes over-saturated; this result is assisted by loss of heat, with which the steam unavoidably meets; to add to the general shortcomings, there is, generally, in such boilers, no opportunity for heat in the flues to come in contact with surface situated conveniently for the absorption of such heat by the over-saturated steam.

A steam boiler, to produce economical results, should be constructed and set so as to permit a free combustion of the fuel, and give sufficient volume of space for the hot gases to combine, in a manner calculated to effect the utmost production of heat due to the fuel consumed.

Combustion of fuel is the *chemical combination* of the substance of the fuel with the oxygen of the air; and now, before progressing any further with our subject, it will be desirable to present a few facts in Natural Philosophy.

A mechanical mixture: Is a *composition* in which the ingredients retain their natural properties; steam is a mechanical mixture of heat and water; atmospheric air is an invisible gas, produced by the mechan- mixture of two other gases, viz., oxygen and gen.

chemical combination: is *an action*, during which rtain elements and substances are absorbed and de- oyed, in the production of some other element or substance. Heat is a product of the chemical combination of the element oxygen with a combustible substance; an duce the maximum volume of heat

from a given weight of fuel, it is necessary that a proper quantity of oxygen, and under correct conditions, be admitted to the furnace and combustion chamber.

The maximum rate of heat having been provided for, the surface of the boiler exposed for its operation should be of sufficient extent to allow the necessary time for transmission of heat to the contained water; when the heating surface is insufficient, the heat is certain to be carried through the flues or tubes and into the up-take, before it (heat) can be absorbed to an economical extent.

There must be, also, ample room for the escape of steam to the surface of the water, and after it has passed above the water, it would seem as though it was necessary to bring it (steam) again in contact with some heating surface, to thoroughly complete the evaporation, and even superheat the steam slightly, before it is finally allowed to pass to the engine.

Cases have been known in which the steam was apparently superheated to a considerable degree at the point where it entered the pipe leading to the engine, but, on reaching the steam chest, had relapsed to the temperature due to the pressure, although the pipe was protected from radiation in a manner that would forbid the supposition that heat enough had escaped to make the difference; the facts of the case were most probably, that the extent of heating surface in the boiler was excessive in proportion to the quantity of water, and also very effectively situated, so that the steam, having an exceedingly favorable opportunity for escape to

and above the surface of the water, was generated and passed into the pipe so rapidly that the evaporation was incomplete, although heat in excess of that due to the pressure was carried by the steam, and during the passage through the steam pipe to the engine, sufficient time elapsed to allow the apparent surplus heat to be absorbed by the excess of moisture. With the ordinary horizontal tubular boiler, the production of dry steam is a very difficult task, unless some considerable heat is wasted; for the reason that it would be necessary to operate the boiler as near its capacity as possible, without causing it to prime, and to do this, comparatively "hard firing" would be unadvoidable.

If the steam is not a trifle superheated when leaving the boiler, it is hardly possible for it to be dry at the engine.

Engine cylinders without steam-jackets, when working steam expansively, must necessarily indicate some symptoms of moisture, even when dry or superheated steam is used, because there is no opportunity for additional heat to enter the cylinder after the cut-off valve has closed, and the loss of heat by the iron, resulting from the peculiar effects of expansion of the steam, must be made good from somewhere, and that source is eventually the condensation of a portion of initial steam at the next stroke of the piston.

We may calculate, theoretically, the gross dynamic ergy that should be developed from a certain weight fuel, but the actual operation of the best-known actice must necessarily fall far short of the estima-

tion, unless the boiler and furnaces can
structed that there will be absolutely no es
and the boiler-room and all the appliai
under such conditions, would indicate a
corresponding to that due to the weather
not, of course, be any heat escaping from
If we could thus burn fuel and produce st
the slightest loss of heat whatever, it would
to convert it into dynamic energy, until the
of the steam was reduced to that of the
water used during the operation: assumi
water to be at a temperature of 60° Fal
must be expanded down to that degree, a
would then indicate a pressure of consi
than one pound per inch above an absol
or about 14.5 pounds per inch below the
ordinary steam pressure gauge.

In order to comprehend the nature of
will be necessary to become thoroughly
with a few facts concerning the air we
establish such facts so firmly in the mi
may be referred to as readily as to the
figures that form the basis of every-day
In the first place, the fact must be clearly
that the air in which we move is simply
gas; the height or depth of this gas or
from sea level, has been variously estin
will serve our present purpose to assum
miles in a vertical direction from the surfa
to the upper surface of this stratum of air.

vacuum gauge exhibits the pressure below that line: when the steam gauge attached to a boiler indicates a pressure of 100 pounds per inch, the pressure within boiler is actually about 114.7 pounds per inch, but 14.7 pounds of the pressure is balanced by the air outside of the boiler, and the straining pressure is only 100 pounds. In calculating expansion of steam, the pressure required to balance that of the air must be added to the indication of the steam gauge, the same being the total pressure of steam above an absolute vacuum.

In continuing our subject we have to deal not only with the economical expenditure of heat, but quite as much with the ways and means of producing, preserving, and conveying it to the place where it is to do its work. The direct object in view, in this particular branch of the general operation, is to consume the least value of fuel on the grates, and let the least number of heat units escape.

When a man has accepted any certain thing as a fact, it is a law of his nature to endeavor to strain everything of similar nature to it, and to be astonished if the second thing does not strain without breaking. For years it was reasoned that steam, like air and similar gases, was a very bad radiator and absorber of heat, and every experiment in cylinder operation that argued to the contrary was set aside as doubtful, or was most thoroughly gone over and examined to find the "error." But about ten years ago, Prof. Tyndall, after a series of careful and thorough experiments, gave to the world the fact that the vapor of water would absorb and

radiate heat several thousand times more rapidly than dry air would do so. And yet, for years men had known that steam would rush into a condenser and give up its heat so nearly *instantly*, that a sensitive vacuum gauge in full communication with the condenser would give but slight evidence of the transmission of hundreds of heat units through the chamber.

Before reaching a conclusion in regard to the expansion of steam, the engineer is confined to several important questions, and these questions require different answers under different conditions. An investigation to determine the number of volumes to which steam can be profitably expanded, gives rise to sub-investigations to determine the *quality of the steam;* the nature of the valve gear, proportions of steam ports, and other particulars concerning the construction of the intended engine, claim a share of attention. The items of piston speed, rate of reciprocation, weight of the moving parts, etc., etc., enter into the consideration.

The conversion of heat into work during expansion is accompanied by some very curious and interesting incidents, and, like all good things, reacts in a disadvantageous manner when carried too far. The detraction does not come from any cessation of the primary benefit for which expansion is instituted, but from the increase in the power of the evil genius, "condensation," with which the operation is associated, even in its lowest grades. But the two are inseparable, unless certain precautions are taken before expansion begins. The very thing from which the

benefit is derived is the root of the evil referred to, viz., the loss sustained by the expanding steam, of the heat that is converted into work. The mean temperature of the cylinder under ordinary conditions is never up to that of the initial steam, and the higher the ratio of expansion to do a certain value of work (and, consequently, the higher the initial pressure and temperature, and also the shorter the cut-off), the lower the temperature of the cylinder is in proportion.

The obvious reason for this fall in temperature, incidental to the shortening of the cut-off, is, that the expansion curve falls from the point of cut-off nearer vertical at short than at long cuts, and there is proportionately very much more surface exposed to a comparatively "cooler" body of steam in the high than in the low grades. For expansion of ten volumes, the latter half of the curve does not depart very much from a parallel to the atmospheric line, while for four volumes a totally different appearance presents itself, showing that during the former (ten) the cylinder was exposed to a much lower temperature, and for a longer time, than during the latter.

Hence the economy of expansion, and, therefore, the extent to which it is desirable to carry it, depend chiefly upon the success with which the loss of the heat converted is made good. The abstraction of heat, re-evaporation of water set free, and subsequent condensation of initial steam during one cycle, is comparatively insignificant; and if each revolution made good its own losses, no serious harm would follow

that it pays to employ, as attendants for engines and boilers.

Developments are being made which indicate the necessity of the degree of super-heat bearing a specific relation to the grade of expansion, and these developments plainly tell us why the practice of superheating has been unsuccessful by not acquiring a sufficiently high temperature, and hence of not much benefit in some cases; and also why, in other cases, it has failed by indulgence to excess, and thereby burned out the packing and injured the cylinder and valves.

It would seem that the degree of super-heat must be as closely looked after as the pressure of steam in the boiler; and its relation to the grade of expansion suggests the idea of regulating the super-heater automatically, to correspond to the automatic control of the cut-off.

As has been previously intimated, steam economy exclusively is not the only desideratum to be looked for in steam engines. The extent to which it is carried must depend upon the relative expense incurred in effecting the expansion, and also upon the means which must be employed in utilizing it under the conditions which accompany the undertaking in hand.

Assuming that we can manage to expand the steam and avoid loss of heat to the utmost extent compatible with the laws of radiation, absorption, etc., and the use of iron cylinders, one of the first obstacles to be encountered is the fact that the energy expended by the steam is very far from being uniform. At the begin-

ning of the stroke the impulse is greatly in excess of all demands, while during the latter part of the stroke the pressure on the piston falls far short of that required to drive the load. Hence, if we *must* use expansion, a suitable *reservoir* must be furnished to receive this excess of energy, and be so related to the general mechanism that the effect will be uniform throughout the stroke. This reservoir may consist either of the ponderous moving parts of the engine, such as the balance wheel, cross head, connecting rod, etc., etc.—the inertia of these parts absorbing the surplus energy during the early part of the stroke, and giving it out again gradually as the pressure falls during the latter portion—or, by the use of compound engines, the pressure may be distributed by the use of a receiver of some magnitude between the cylinders, working steam in conjunction with each other, in which case the inertia of moving parts is of little or no importance in the matter of distribution.

CHAPTER II.

THE PROPERTIES OF WATER.*

WATER was supposed to be an element unti
ley, late in the eighteenth century, discove
when hydrogen was burned in a close vessel w
deposited on its sides. (It has been shown
combustion of hydrogen requires eight p
weight, of oxygen, and vapor of water is the r

It was not, however, until Cavendish and I
investigated water that its chemical composi
determined.

The several conditions of water are usually
the solid, the liquid, and the gaseous. Two co
are covered by the last term, and water shoul
derstood as capable of existing in four differe
tions—the solid, the liquid, the vaporous, and
eous. At and below 32° Fahr. water exist
solid state, and is known as ice. According
Rankine, ice at 32° has a specific gravity of .9
a cubic foot of ice weighs 57.45 lbs.

When water passes from the solid to the liqu
heat is required for liquefaction sufficient to el
temperature of one pound of water 143° Fah
is termed the latent heat of liquefaction. Ac
to M. Person, the specific heat of ice is .504,
faction 142.65.

* Hill.

From 32° to 39° the density of water increases: above the latter temperature the density diminishes.

Water is said to be at its maximum density at 39°, and under pressure of one atmosphere weighs, according to Berzelius, 62.382 lbs. per cubic foot. The following formulæ may be used to estimate the weight of water at any other temperature:

$$D=\frac{2\,D'}{\frac{T+461}{500}+\frac{500}{T+461}}$$

where D=weight of cubic foot of water at temperature T′, and D′=weight of cubic foot of water at maximum density. Desired the weight of a cubic foot of water at a temperature of 60°.

$$\frac{62.381\times 2}{\frac{60+461}{500}+\frac{500}{60461}}=\frac{124.762}{2.0016}=62.331$$

Water is said to vaporize at 212° Fahr., and pressure of one atmosphere (14.7 lbs.), but Faraday has shown that vaporization occurs at all temperatures from absolute zero, and that the limit to vaporization is the disappearance of heat. Dalton obtained the following experimental results on evaporation below the boiling temperature:

Temp.	Rate of Evaporation.	Barometer.
212	1.00	29.92
180	.50	15.27
164	.33	10.59
152	.25	7.93
144	.20	6.488
138	.17	5.565

From this, the general law is deduced that t
surface evaporation is proportioned to the ela
of the vapor.

Thus, suppose two tanks of similar surfa
sions and open to the atmosphere, one contain
maintained constantly at 212° Fahr., and the o
taining water at 144° Fahr.

Then for each pound of water evaporated i
tank, five pounds will be evaporated in the

It should be understood that the law of Da
good only for dry air, and when the air c
vapor having an elastic force equal to that of
of the water, the evaporation ceases.

The boiling point of water depends upon
sure. Thus at one atmosphere (14.7 lbs. 2
ometer) the temperature of ebullition is 21
a partial vacuum, or absolute pressure of o
(2.037″ of mercury) the boiling point is 10

Upon the other hand, if the pressure be
absolute (60 lbs. by the gauge), the tempe
evaporation becomes 307° Fahr.

The relations of temperatures and press
been made the subject of special investigation
time of Watt, down to the celebrated exper
Regnault, which have been accepted as con
far as they extended.

The relations of pressure and density, how
not been determined by experiment. Mes
bairn and Tate have investigated this pro
deduced a formula, but late experience has s

quently, some idea of the magnitude of the task of accomplishing perfect combustion may be arrived at.

We thus see that each pound of coal requires 138 cubic feet of air for its perfect combustion; that is, to convert the carbon into carbonic acid. Just in proportion as the quantity is deficient is combustion imperfect, while a surplus quantity is a change of evils, since all the air, which passes through a fire without giving up its oxyen to the fuel, will abstract heat and give nothing in return. In all likelihood, in practice, twice the quantity passes through the fuel which chemistry tells us is needed for combustion. Could we isolate each piece of fuel in such a manner that the whole of its surface would be surrounded by the incoming air through the grate, we might be able to come nearer the law of chemical affinity, but there are practical difficulties in the way of this; nevertheless, there is room for improvement over what might be called the rule of thumb practice universally in use.

The question resolves itself into this: *How*, *where*, and *when*, shall air be admitted to the fuel to get the best possible results?

Since the advent of the steam engine hundreds of devices have been used for the more perfect combustion of fuel, and there probably never was one of them that was of general application. To burn fuel a grate is necessary, and it must possess, first: the greatest possible amount of open space per square foot for the ingress of air to the fuel; second, it must have lasting qualities; third, and not least, it shall require as little

manual labor as possible to clean and make a fresh fire as often as necessary. It is here that combustion is made to begin, by placing on the grate the kindling wood or other like matter, the carbon of which unites at a comparatively low heat with the oxygen of the air, and creates sufficient heat to cause the carbon of the coal to unite, also, with the oxygen of the air. The ability to pass air through the fire depends on the temperature and height of the column of air in the chimney; but from the time that the coal begins to burn, leaving its ash on the grate, the passage of the air through the fuel is being obstructed, until, finally, a sufficient quantity cannot enter to the coal or carbon to convert it into heat fast enough, when the removal of the obstruction (the ash) becomes an imperative necessity. But, is not this the place to admit and control the air, according to requirement? It is here that the new condition of the fuel begins. What other place seems so propitious to admit at will an equivalent of oxygen to its affinitive (carbon) as here? But to control the supply it is evident that some other means than the chimney must be resorted to. Its power to draw air through the grate depends on the intensity of the heat which can be created or made to pass into it.

Aside from the expense consequent upon operation, were it practicable to [illegible] there are other considerations [illegible] control. Barometric [illegible] often of sufficient [illegible]

The less often the furnace doors are opened the more regular will be the supply of steam. If the fire is replenished with fuel oftener than can be avoided, not only does the fresh fuel lower the temperature in the furnace, but the ingoing air through the open doors passes rapidly along and into the flues, lowering the temperature still further as it goes.

Theoretical firing says, a small quantity of fuel at a time; *practice* says, as large a quantity as kind and size of fuel and draught of chimney will admit.

A small quantity of fuel makes a small quantity of heat, and, per contra, a greater quantity of fuel will make a larger quantity of heat. When a boiler has to supply a quantity of steam which is much less than its capability, then theoretical firing becomes practical. Under such conditions it is possible to supply a small quantity of fuel, applied at the right time, and to maintain a given pressure of steam without moving the damper, for hours. Less fuel will be consumed than if it were supplied in a quantity necessitating the whole opening of the damper to get the larger quantity of fuel in a brisk state of combustion as soon as possible, thereby preventing a lowering of the steam pressure, caused by the larger quantity of fuel cooling off the furnace on its introduction more than the small did. The increased quantity of air, much in ical requirement for perfect combustion, much of the heat previously existing in the flues when light firing is being

To admit air above the fuel at ordinary temperatures, and in excess of absolute requirements, is, then, the opposite of what is desirable.

Admission of air without regulation must fail in general adaptation. Success may, to a certain extent, follow in some cases; but, as a general principle, adding to the supply of atmospheric air above or beyond the fire, without some definite knowledge of absolute requirement, is just as likely to defeat the object as to assist it.

The ability to regulate implies a knowledge of the condition of the escaping gases from the burning fuel. Beyond the bridge wall little can be known as to the condition of the gases. If an instrument were devised to show the quality of gases passing underneath the boiler, we should then have some definite knowledge on the subject. Of the fuel on the grate, a practised eye can tell whether it is getting a sufficient supply of air. We have the authority of Mr. John Bourne for the statement: "In all trials it has been proven that the best results have been always attained when all the air has passed through the fire bars." Under the fire bars, then, seems to be the place to admit and regulate the supply of air to the fuel.

If the supply be heated previous to its admission, every degree it is so heated is one degree saved from the fuel in heating it to the combustion point of oxygen with the carbon of the fuel. As to what extent it may be heated, before it would have a destructive effect on the grate, experiment must determine, since

it would not be desirable to increase expenses for repairs. Whatever is done to promote combustion will be a net gain.

Where large or long boilers are in use, rapid combustion is unnecessary; but when short and compact forms are adopted (as, for instance, any of the various forms of tubulars now in use and coming into use), rapid combustion becomes a necessity. To create this, a swift supply of air through the fuel must be provided. The present mode of doing this, is by *sucking* this supply through the fuel, the power of doing it being dependent on the lightness of the column of gases in the chimney. The ability to stimulate the draft depends on the rate of combustion in the furnace. This is never fully controllable, without independent means of quickening combustion when most needed. At no time is quickened combustion more needed than after putting on a new supply of coal, when the energy languishes from the very cause which rendered a stimulus desirable.

This lack of sufficiently rapid or stimulated combustion is particularly noticeable and exceedingly undesirable when boilers are worked quite up to or near their capacity. After a fresh addition of fuel on a grate that already contains so large a quantity of ash as to materially affect the passage of air through it, cleaning the grate to facilitate the free passage of air is impracticable. Practical observation points very strongly to

"some" "of forcing air through the obstruc-

ing combustion until a feasib-

g fresh fires.

said gas within the oven-like arrangement. The heat that could be generated within was intense, being almost a white heat. No experiment was ever tried to ascertain whether there was a gain or not. The plan had its drawbacks, and may have had its advantages, as a promoter of combustion. Until the arch was heated to almost a white heat, there was little effect on the boiler, and it required considerable fuel and time to bring it to that state from starting a fire. Every time fresh fuel was placed on the grate, aided by the flow of air through it, the temperature would be considerably lowered, forming a very good exponent of what takes place in the flues of a steam boiler every time the fires are replenished with fuel.

However complete any arrangement may be for the attainment of perfect combustion, unless judicious means are employed for applying the heat, the best efforts may be made nugatory. The proper setting of a boiler is as important as the boiler itself. Co-operation between owners and builders of steam boilers would do much towards attaining the best possible results, as there is little reliable information of every-day practice and results in regard to the steam boiler and its fuel. There is one point that should not be forgotten by those who attempt to improve combustion by means of any system, and that is, the fireman possesses more control over the action of the fire than any additional apparatus that was ever devised.

pears that about 14 per cent. is about a maximum efficiency with our present knowledge of construction. The object of this chapter is, however, not to discuss the economy of steam machinery, but to show the necessity for an exact knowledge of the thermal value of steam, in estimating the economy of engine and boiler performance.

To illustrate the effect of a lack of knowledge of the quality of steam furnished by boilers, let us suppose a temperature of feed of 212° Fahr., an expenditure of coal of 1,000 pounds, a consumption of feed-water of 12,000 pounds, and a boiler pressure by gauge of 125 pounds. The apparent evaporation from the temperature of feed in this instance is twelve pounds of steam to one of coal. Without information to the contrary, and in accordance with the usual practice, we would accept this as the evaporation, and pronounce the result as extremely satisfactory. Suppose, however, the temperature of the steam, instead of being at saturation (1,221.53 units), contained as a mean per pound only 1,135 units; then the actual evaporation, instead of being twelve to one, would be ten and eight-tenths to one, and this instance supposes an efficiency of furnace and boiler of nearly 75 per cent., and a thermal 'ue of 15,000 units per pound of coal; in brief, sup- s a quantity of coal and efficiency of furnace rarely ined. None of the usual devices appli d to steam ers are capable of measuring the thermal value of am, and recourse is had to special apparatus for this rpose. Two distinct forms of calorimeter have been

used; one the continuous calorimeter, in which the condensation of a certain small percentage of the steam is maintained during the entire trial of a steam engine or boiler, and the other the intermittent calorimeter, with which at stated intervals known weights of steam are drawn from the boiler or steam pipe and condensed in known weights of water.

The continuous calorimeter consists usually of a coil of brass pipe or copper of ¼ to ½ inch diameter of bore, containing 30 to 50 lineal feet. This coil is placed within a tin can, through which the circulating water passes from below upward. The upper end of the worm is connected with the steam pipe or steam drum of the boiler, and the lower end terminates in a neck which delivers the condensed steam into a receptacle mounted upon a carefully-balanced scale, with which the condensation is weighed from time to time and dumped. The circulating or condensing water is measured by tanks of known capacity, or through a Worthington meter, the error of which is known by test. Standing thermometers are located as follows: One in the injection pipe, by which the circulating water enters the apparatus; one in the overflow nozzle, by which the circulating water leaves the apparatus; and one in the neck of the worm from which the water of condensation flows. Should there be an indication from the calorimeter data of superheat in the steam, an additional thermometer should be inserted in the head of the worm or in the steam pipe leading to it, to measure the superheat independently and

place; and that additional temperature of 860·2 is necessary to vaporize the water so heated; and the discrepancy in the thermal value of the steam applies to the temperature of vaporization, when the water entrained as primage becomes

$$100 \times \frac{63{\cdot}18}{860{\cdot}2} = 7{\cdot}35 \text{ per cent.}$$

The intermittent calorimeter consists of a water vessel (preferably of wood, to avoid transfer of to or from the contents thereof by conductio radiation) mounted upon a sensitive scale, into a known weight of water is drawn. A small pipe, usually three-quarters of an inch in dia closely connected with the main steam pipe or drum of the boiler, dips into the vessel on the and is provided with a cock or open-way valve to late the delivery of steam into the weighed quan water. The temperatures are taken with a hand mometer. As suggested, a known weight of wa first weighed into the tank on the scale, usually convenient quantity to estimate from, as 100 pounds, of which the probable condensation small steam pipe usually forms a part. The am of condensation which will collect in the steam between observations will vary with the qual steam, and must be blown out to clear the pipe the weighed quantity of steam to be condensed is in. The weight of water and condensation blow of the pipe having been justified, the temperatu

the contents of the tank is carefully taken wit liable thermometer, and 5 or 10 pounds of steam in and condensed. (The weight of steam con should be as large as consistent with a limited t ature of the contents of the tank on the scale, tain a high range of temperature; since err weight are less liable to occur than errors of te ture, and the greater the range of the mercu smaller the effect of errors of observation.) T sired weight of steam having been condensed, t through the pipe is promptly suppressed and a temperature of the contents of the tank is take first temperature from the second temperature sents the range of the contents of the tank. T trate the principle of the intermittent calorime the following data be assumed:

Weight of condensing water	100 pound
Weight of steam condensed	5 "
Initial temperature condensing water . . .	60 F.
Final temperature condensing water . . .	115 F.
Range	55 F.

and the temperature of steam is

$$115 + \frac{100 \times 55}{5} = 1{,}228 \text{ F.}$$

Supposing steam, as before, at a pressure a of 150 pounds, the difference between the qu the illustration and saturated steam is 4·82 uni responding to a superheat of

$$\frac{4{\cdot}82}{0{\cdot}475} = 10{\cdot}15 \text{ F.}$$

We shall refer only to a few experiments to show the value of investigations of this class. The first results we will examine are from a series of four experiments upon boilers set with smoke-preventing furnaces for the Cincinnati Industrial Exposition for 1879.

The first case was a return tubular containing 963.64 superficial feet of heating surface, and worked at a capacity equivalent to 2.77 pounds of steam per foot of heating surface per hour, which gave a temperature of steam of 960.46 units, indicating, with a pressure by gauge of 38.75 pounds, a primage of 26.26 per cent. The apparent evaporation from the temperature of feed (70.02° F.) per pound of coal was 7.59 but the actual evaporation from same temperature was only 5.6 to one.

The second case was a return flue boiler containing 519.45 superficial feet of heating surface, and worked at a capacity equivalent to 1.73 pounds of steam per foot of heating surface per hour, which gave a temperature of steam of 864.73 units, indicating with a pressure by gauge of 80.29 pounds, a primage of 29.13 per cent. The apparent evaporation per pound of coal from the temperature of feed (166.01 F.) was 5.84, the actual evaporation from same temperature was to one.

The third case was a battery of 2 return tubular boilers containing 880.16 superficial feet of heating surface, and worked at a capacity equivalent to pounds of steam per foot of heating surface per

which gave a temperature of steam of 1,005.93 units, indicating with a pressure by gauge of 76.18 pounds, a primage of 23.19 per cent. The apparent evaporation per pound of coal from the temperature of feed (169.11° Fahr.) was 9.69, but the actual evaporation was 7.45 to one.

The fourth case was a direct tubular boiler containing 327.79 superficial feet of heating surface, and worked at a capacity equivalent to 2.96 pounds of steam per foot of heating surface per hour, which gave a temperature of steam of 1,441.35 units, indicating, with a pressure by gauge of 81.60 pounds, a superheat of 18.83 per cent. The apparent evaporation per pound of coal from the temperature of feed (74.55° Fahr.) was 8.80, but the actual evaporation upon the basis of saturated steam was 10.66 to one. This boiler was set and worked simply for test purposes, and was furnished with superheating surface. The continuous calorimeter was used in these experiments. The next results to which I shall refer are the calorimeter tests for quality of steam during the trials of steam engines at the Millers' Exhibition, Cincinnatti, 1880. In this instance the experiments were all made with the same

s, operated under approximately the same con-
from day to day. The boilers, two return
, contained 137.24 superficial feet of heating
:, and were worked at the following capacities
nds of steam per foot of heating surface per
, for six different trials: 2.53, 2.42, 2.32, 2.41,
, and 2.63—with corresponding temperature of

steam of 1,243.84 units, 1,211.3 units, 1,315.86 uni
1.255.74 units, 1,301.65 units, and 1,313.11 units. (
these temperatures only one, the second, indicat
primage; all others exhibit a slight superheat. T
primage at 92.54 pounds pressure by gauge in t
second experiment was 0.46 per cent. The percer
age of superheat at 92.50 pounds pressure by gau
in the first experiment was 2.3; in the third expe
ment, with steam pressure at 91.65 pounds by gaug
8.3 per cent.; in the fourth experiment, with stea
pressure at 91.48 pounds by gauge, 3.34 per cent.;
the fifth experiment, with steam pressure at 91.
pounds by gauge, 7.09 per cent., and in the sixth e
periment, with steam pressure at 91.54 pounds
gauge, 8.06 per cent. The continuous calorimeter w
used in these trials.

The former results were from four different boile
of different forms and dimensions, and operated at d
ferent steam pressures and rates of evaporation, with
range in the quality of steam from 19 per cent.
superheat to 29 per cent. of primage; while the last s
results were all from the same boilers, operated
different times, under approximately the same stea
pressure and rates of evaporation, with a range in t
quality of steam from 8.3 per cent. of superheat to
per cent. of primage. From which it appears th
with the same boiler or boilers, operating under sir
ilar conditions, an approximately uniform quality
steam should be had, and that the quality of stea
in any one instance cannot be assured for anoth
unless the conditions are precisely alike.

25.90 to one. The boiler was worked at a capacity equivalent to 8.49 pounds of steam per foot of heating surface per hour, with a temperature of steam of 1,150.98 units, indicating at 105.5 pounds pressure, by gauge, a primage of 5 per cent. The apparent evaporation per pound of coal was 4.45, and the actual evaporation was 4.09 to one.

For the second and third trials the heating surface by the introduction of a water bridge into the fire box was increased to 300.7 superficial feet, with a ratio of heating to grate surface of 41.67 to 1. During the second trial the boiler was worked at a rate of evaporation equivalent to 9.39 pounds of steam per foot of heating surface per hour, with a temperature of steam of 1,181.76 units, indicating at 98.25 pounds pressure by gauge, a primage of 4.33 per cent. The apparent evaporation in this case was 7.58 pounds, and the actual evaporation 7.25 pounds of steam to 1 of coal.

During the third trial the boiler was worked at a rate of evaporation equivalent to 9.77 pounds of steam per foot of heating surface per hour, with a temperature of steam of 1,259.29 units, indicating a superheat of 88.67° F., at a pressure, by gauge, of 100.7 pounds. The apparent evaporation was 6.41 pounds of steam per pound of coal, and the actual evaporation upon the basis of saturated steam was 6.65 to 1. The rate of combustion and evaporation was higher for the third trial than for the second, with a better quality of steam and a reduced economy. In these trials the coal was burned within five or six per cent. of the total weight

good makes of thermometers, then I can conceive no other objections to accepting the results of calorimeter experiments than the personal errors of observation which pervade all mechanical investigations.

If the power of steam engines is to be measured by the indicator, or the less reliable dynamometer or friction brake; if the economy of boilers and engines is dependent upon the accuracy of weighing scales; if steam pressures are to be taken from spring gauges and temperatures read from mercurial thermometers and such results are held to be reliable for absolute and comparative effect; then the same reliability must in simple justice, be accredited the calorimeter, for it depends solely upon correct weights and temperatures and involves no complex or uncertain quantities in the operation.

space. The force exerted by a single man might be made to move a weight equal to all the buildings in New York city—strength of material and time permitting. The screw, hydraulic press, etc., are merely devices which require that a small propelling force move through a comparatively great distance to effect the small movement of a heavy weight. The lever illustrates the action of all mechanical devices to apply power. The device, whatever it may be, is merely the *harness* that makes the strength of the horse available in drawing the wagon; but in no way increases the horse's strength. Thus in Fig. 1 we have a lever, the long end being ten feet, to which is attached a ten pound weight. The short end is one foot and supports a 100 pound weight. It is plain that—not taking into consideration the weight of the lever itself—the weights exactly balance each other. If we wish to raise the 100 pounds one foot, it is plain the ten pounds must move through *ten* feet to accomplish it, as the long end is ten times longer than the short end. From this we can deduce a very useful rule of universal application, as follows: The propelling force, multiplied by the distance through which it moves, equals the resistance or weight, multiplied by the distance through which it moves to balance the former. The practical application of this may be seen in the lever again. Thus we wish to raise 200 pounds through one foot with the force of ten pounds. To do this it is plain that the 10 pounds must move through a greater distance than it did to raise the 100 pounds, and to do this its end

Notice how many feet a point on the end of the rope you pull on moves through, to raise the hook to which the load is attached *one* foot. Suppose the point moves through eight feet while the hook moves one, the leverage is 8 to 1, and it is plain that if you exert 100 pounds with your hands you will raise a load of $8 \times 100 = 800$; but your hands pull the rope through *eight* feet, and your load (which is eight times the power) moves through but *one* foot. The combination of the screw and lever comes under this rule. Thus notice how many inches the end of the lever, to which the power is attached, moves through to advance the screw *one* inch. Suppose it moves through 100 inches, the leverage is 100 to 1, and if you pull 100 pounds on the lever you will lift $100 \times 100 = 10{,}000$ pounds, *but only through one inch, while your power travels through 100 inches.*

The wedge's force may be ascertained, by dividing the distance it travels into the log being split, by the distance the crack or split opens; the quotient is the leverage or advantage, which multiplied by the force of the blow, equals the rending or splitting force. Again, the pressure on an engine's piston $\times$, by the space it moves through in a given time, is the power it exerts, theoretically. If we wish to double the force of an engine, we double the number of feet the piston travels in a given time, or we may double the steam pressure; thus increasing the force, or the distance traveled in a given time, increases the effect proportionally.

dency to fracture the pin put through the line *c b*; that is, lift or tear the part A from the part B. The safe tensile load for cast iron is about 2,000 pounds per square inch of section; hence to have the hub large enough, it must present an area of solid metal of 20,000÷2,000 = 10 square inches. The portion or section of the crank, *j k*, may be ascertained by considering the crank a beam, fixed at one end and loaded at the other. The section *d e* must be twice as strong as *j k*, as it moves through but half the distance that *j k* does, and the section *h i*, moving but one-third the distance, must have an area of three times that of *j k*. Thus, in designing any machine, after ascertaining the motion and strain on the leading part, we may proportion the balance from it

in 1828, and were the first railroads intended for public use. Others soon followed in different parts of the country: notably, the New Castle & Frenchtown Railroad, connecting the Chesapeake and Delaware bays, which for many years was the connecting link and great thoroughfare for passenger travel between the North and South. This railroad, which was finished in 1831, was sixteen (16) miles long, and at that time the best-laid road in the country.

CHAPTER VIII.

FIRST AMERICAN LOCOMOTIVE.

FIGURE 4 shows a sketch of the first locomotive built in America. It was built by the venerable Peter Cooper, of New York city—a name well-known and deservedly respected throughout the entire length and breadth of this country. The following is a letter written by him to Mr. Brown, the author of "The History of the First Locomotive in America." The letter was written to explain the cause which led the writer to deviate from the path of his legitimate business to become the builder of a locomotive. Our cut, for which we are indebted to the *Railroad Gazette*, of New York, represents the locomotive below referred to:

"NEW YORK, MAY 18, 1869.

"MY DEAR SIR: In reply to your kind favor of the 10th inst., I write to say that I am not sure that I have a drawing or sketch of the little locomotive placed by me on the Baltimore and Ohio Railroad in the summ[illegible] 1829, to the best of my recollection.

[illegible] engine was a very small and insignificant affair. [illegible]ade at the time when I had become the owner [illegible]e land now belongi[illegible] Canton Company, [illegible]alue of which, I [illegible]d almost entirely [illegible]on the succes[illegible]d Ol[illegible]d.

"At that time an opinion had become prevalent that the road was ruined for steam locomotives, by reason of the short curves found necessary to get around the various points of rocks found in their course. Under these discouraging circumstances, many of the principal stockholders were about abandoning the work, and were only prevented from forfeiting their stock by my persuading them that a locomotive could be so made as to pass successfully around the short curves then found in the road, which only extended thirteen miles, to Ellicott's Mills.

"When I had completed the engine, I invited the directors to witness an experiment. Some thirty-six persons entered one of the passenger cars, and four rode on the locomotive, which carried its own fuel and water; and made the first passage, of thirteen miles, over an average ascending grade of eighteen feet to the , in one and twelve minutes. We made the return trip y-seven minutes.

PETER COOPER'S LOCOMOTIVE.

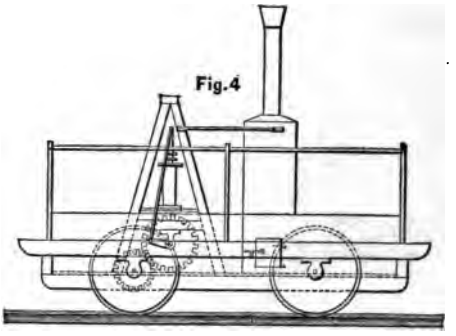


Fig.4

THE FIRST ONE BUILT IN AMERICA.

I regret my inability to make such a sketch of the

engine as I would be willing to send you at this moment, without further time to do so.

"Yours, with great respect,

"PETER COOPER."

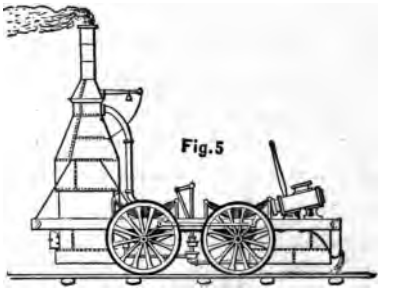
The boiler of Mr. Cooper's engine was not as large as the kitchen boiler attached to many a range in modern mansions; it was of about the same diameter but not more than half as high. It stood upright in the car, and was filled above the furnace, which occupied the lower section, with vertical tubes. The cylinder was but three and a half inches in diameter, and speed was gotten up by gearing. No natural draught could have been sufficient to keep up steam in so small a boiler; and Mr. Cooper used, therefore, a blowing-apparatus, driven by a drum attached to one of the car wheels, over which passed a cord that in its turn worked a pulley on the shaft of the blower. Among the first buildings erected at Mount Clare was a large car-house, in which railroad tracks were laid at right angles with the road track, communicating with it by a turn-table, a Lilliputian affair indeed compared with the revolving platforms, its successors, now

this car-shop Mr. Cooper had his engine, and steam was first raised. With his own hands he opened the throttle, admitted the steam into the cylinder, and saw the crank-substitute operate successfully with a clacking noise while the machine moved slowly forward with some bystanders who had stepped upon it. And the first locomotive for rail-

road purposes ever built in America; and this was the first transportation of persons by steam that had ever taken place on this side of the Atlantic on an American-built locomotive.

Mr. Cooper's success was such as to induce him to try a trip to Ellicott's Mills, on which occasion an open car, the first used upon the road, having been attached to the engine, and filled with the directors and some friends, the first journey by steam in America on an American locomotive was commenced. The trip was most interesting. The curves were passed without difficulty, at a speed of fifteen miles an hour, and the grades were ascended with comparative ease. The day was fine, the company in the highest spirits, and some excited gentlemen of the party pulled out memorandum books, and, when at the highest speed, which was eighteen miles an hour, wrote their names and some connected sentences, to prove that even at that great velocity it was possible to do so. The return trip from the Mills, a distance of thirteen miles, was made in fifty-seven minutes. This was in the summer of 1830: but the triumph of this Tom Thumb engine was not altogether without a drawback. The great stage proprietors of the day were Stockton and Stokes; and on that occasion a gallant gray, of great beauty and power, was driven by them from town, ttached to another car on the second track—for the ompany had begun by making two tracks to the Mills -and met the engine at the Relay House on its way ck. From this point it was determined to have a

The second locomotive ever built in this country, and the first for actual service on a railroad, was the "Best Friend," built by the West Point Foundry, New York., for Mr. E. L. Miller, of Charleston, S. C., for use on the South Carolina Railroad. The "Best Friend," Fig. 5, was a four-wheel engine, all four wheels being drivers. Two inclined cylinders, at an angle, working down on a double crank inside of the frame, with the wheels outside of the frame, wheels connected together on the outside by side rods. The wheels were made with iron hubs, wooden spokes and felloes, with iron tires, and iron webs and fins in the wheels to connenct the outside rods to.



BEST FRIEND, 1830.

The boiler was a vertical one, shaped something like a porter bottle; the boiler set in the centre of the four wheels, with connecting rods running by it to the crank shaft. The cylinders were 6 inches in diameter by 16 inches stroke; the wheels about 4½ feet in diameter. The whole machine weighed about 4½ tons. It was sent to Charleston, S. C., in the fall of 30, and put to work soon after.

ran long and successfully. One day while Mr. rell, the engineer, was making up the train (there

being no conductors or brakemen in those days), the negro fireman put his weight on the safety valve to prevent the steam escaping, and exploded the boiler, causing his own death, with that of another negro, and the scalding of Mr. Darrell. In the "Best Friend," we had not only the first American locomotive in actual use, but also the first locomotive boiler explosion on record.

The third locomotive built in America was called the "West Point," built in 1830, by the West Point Foundry of New York, from plans by Horatio Allen, Esq., for the South Carolina Railroad, and set to work in Feb., 1832. This locomotive had the same size of engine frame, wheels, cranks, etc., as the "Best Friend," but had a horizontal tubular boiler. The

Fig. 6
WEST POINT, 1830.

[illegible] 2½ inches in diame[illegible]er, and six feet long. [illegible]king of this engine in actual service was [illegible]actory. Mr. Nicholas W. Darrell was ap- [illegible] engineer, and ran it from the time it was put [illegible] road. As he had charge of the "Best Friend" [illegible], he was the [illegible]merican locomotive engineer;

Mr. Allen and Mr. Cooper having run engines only on experimental trips.

The fourth American-built locomotive was the "De Witt Clinton," built also by the West Point Foundry,

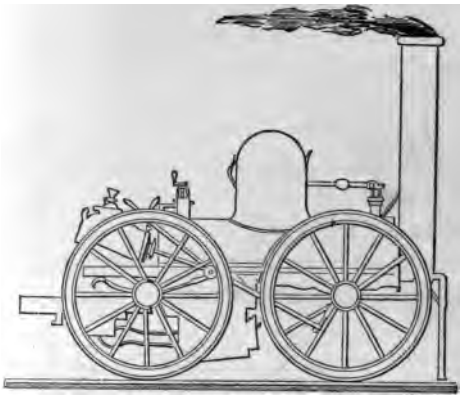
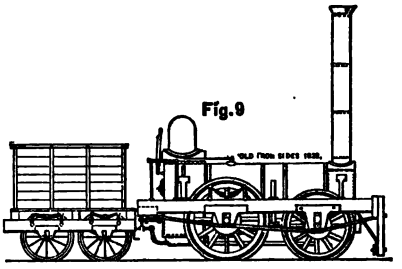


FIG. 7. DE WITT CLINTON, 1831.

for the Mohawk and Hudson River Railroad, New York, in 1831, shortly after the "Best Friend" and "West Point" were completed and shipped to Charleston. This engine had two cylinders 5½ inches in diameter, and 16 inches stroke; four wheels, all drivers, which were 4 feet 6 inches in diameter. The hubs were made of cast iron, spokes of wrought iron, with inside cranks and outside connecting rods to connect all four wheels. The boiler was a tubular one, with a drop furnace, two fire-doors, one above the other, copper tubes 2½ inches in diameter, and six (6) feet long. The cylinders were inclined, and the pumps were worked by bell cranks. This engine weighed

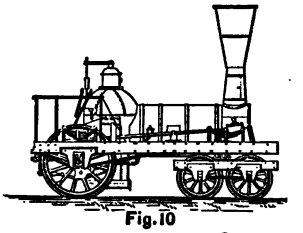
hibition, Philadelphia, in 1876, and there are one or more still used as shifting engines at Mount Clare Station, Baltimore, Maryland.

In November, 1832, M. W. Baldwin, the founder of the celebrated Baldwin Locomotive Works, built a locomotive named the "Old Ironsides," for the Camden and Amboy R. R., which did good service for 20 years. It was a close copy of the English engines used on the New Castle and Frenchtown Railroad, with a few minor improvements. It attained a speed of 28 miles per hour. It is creditable to Mr. Baldwin as an engineer, that this engine was the first and last of his imitations of the English locomotives. He, following the rest of the American builders that had entered the business, aimed too at making an American locomotive, and his second engine and those succeeding it were different in design from the "Old Ironsides."



OLD IRONSIDES, 1832.

In 1834, M. W. Baldwin built for Mr. E. L. Miller, of Charleston, S. C., a locomotive—named after that gentleman—for use on the



THE E. L. MILLER, 1834.

South Carolina Railroad. This engine was a six-wheeled engine, with cylinders 10 inches in diameter, and 16 inches stroke. He made the boiler of a form which remained standard for many years, with a high dome over the fire-box. By the end of 1834 he had built five locomotives, and by this time (1834), locomotive engine building had become one of the leading and most promising industries of the United States. William Norris, of Philadelphia; Hinckley & Drury, of Boston; Ross Winans, of Baltimore, and other builders, entered the field, each and all improving the then existing types, until we have the American locomotive of to-day—one of the most perfect pieces of mechanism wrought out by the hand and mind of man.

CHAPTER IX.

CONSTRUCTION OF LOCOMOTIVES.

A LOCOMOTIVE engine must combine within itself the means for the generation of steam, its application to produce motion within the engine itself, and also the propulsion of the whole upon the road. A complete locomotive engine, therefore, combines three distinct arrangements for realizing these conditions. The source of power lies in the boiler and fire-box; the cylinders, valve, piston, and the various connections, are the means by which it is applied to produce motion within the machine itself; and the wheels by their adhesion, or tractive force, secure the locomotion of the machinery which impels them, and also from their surplus power, above what is necessary to move the engine alone, the drawing of a great load upon the rails. It is, therefore, necessary for the student to understand the construction of each of these parts, and also the general arrangement by which they are combined for the production of power.

Fig. 11 shows, or will serve to show, the general construction of an ordinary eight-wheeled engine, divided in the direction of the length of the boiler, so as to show the entire machinery for generating and applying the power. The boiler *N*, *N*, *N*, in which

ing through them to the water by which they are surrounded, and which generally stands about four or five inches above their upper or top row. It is the surface of the fire-box and these tubes that constitute the heating surface of a boiler. That portion of the boiler above the water level—shown by dotted line 4, 4, 4, is the steam-room of the boiler, and is occupied by the steam generated from the water above and among the tubes and in the water space around the fire-box.

The forward compartment of the boiler, or smoke-box, *A*, receives the products of combustion and the chimney *P* provides for its escape into the open air.

The draught of the fire through the tubes is produced artificially by the escape of the steam from the cylinders of the engine through the exhaust pipe *a* into and up the chimney *P*. The peculiar form given to the boiler, the contact of water with the sides and top of the fire-box, and the great extent of fire-surface afforded by the tubes, secure the rapid production of a vast volume of steam within very restricted limits.

The second division of the entire arrangement of the engine is that in which the power already generated is applied to produce motion within the engine itself. Upon the top of the boiler there is a cylindrical chamber 5, called the "dome," and the pipe—called the "steam pipe," which conveys the steam to the cylinders, penetrates it as seen at *R*. The object of elevating the mouth of this pipe is to prevent the motion of the engine from throwing particles of water into it, to be carried to the cylinders and oppose a

dangerous load to the motion of the pistons. The mouth of the steam pipe *SS*, is covered by a valve *R*, called the "throttle valve," provided with ports or openings to admit steam within it, and the admission of steam is governed by the motion communicated to the valve through a rod attached to the throttle lever in the cab, within easy reach of the engineer. In the figure this valve is represented as open and the steam is passing through the pipe, in which it passes along through the partition between the boiler and smoke-box, and down through the branch-pipe (of which there is one to each cylinder), into the steam-chest *T*. This steam-chest communicates with each end of the cylinder *c*, by passages 6 6, called "steam ports," and the steam is admitted through these passages alternately to each end of the cylinder by the "slide-valve" *7*. Within the cylinder is a "piston" *D*, against which the steam is exerted to produce motion.

In the position given to the valve as shown in the figure (11,) the right-hand passage is open, and is admitting steam to that end of the cylinder, to press the piston in the opposite direction. There is also a qu[illegible]y of steam on the left hand of the piston, which [illegible]oyed in the preceding stroke of the piston [illegible] to the right hand; and its work now being [illegible]s escaping through the left hand passage or [illegible]d turning in a cavity in the under side of the [illegible]nto a thir[illegible]ge—called the "exhaust port," [illegible]linder, and which is situated [illegible]o steam ports already men-

tioned. This steam, called the "exhaust steam," is carried in the last passage a short distance around the cylinder, and passes through an opening on the side of the same into the bottom of a vertical pipe, called the "exhaust pipe" *a*, within the chimney, and from thence escapes to the outer air. The mouth of the exhaust pipe is somewhat contracted, and the resistance given by this contraction to the exit of the steam makes it discharge in a very forcible blast. This powerful draught at the ends of the tubes excites the passage of the heated air through them, and causes a great intensity in the fire. Without this artificial draught, the boiler could not, with its contracted fire surface, generate sufficient steam to supply the cylinders.

We have seen the steam entering by the right-hand passage to the cylinder, and driving the piston to the opposite end of the same. As the piston approaches the left-hand termination of its stroke, the valve 7 is made to shift its position in the steam-chest, and to close the right-hand passage, and at the same time to open the left-hand one. The right-hand passage is fully closed when the piston is within several inches of the end of the cylinder, and the left-hand passage almost at the same time begins to open, so that the full pressure of the steam is exerted against the left-hand side of the piston before it actually has completed its stroke in that direction. This advance of the valve on the piston is called the "lead" of the valve, and when confined within certain limits is found to increase the speed of the engine, as it allows the steam to act with

a concussive force (like that of a spring) at the ends of the strokes, so as to lose no time in changing the motion of the piston. When the piston has commenced its return stroke, and while it is in its motion, the valve moves likewise in the same direction, uncovering the left-hand passage more and more, until, when the piston has returned to the position shown in the figure on the middle of its stroke, this passage is fully open, the same as the right-hand passage, shown in the figure for the preceding stroke. The motion of the valve has transferred the cavity on its under side to the right-hand passage, and the steam, which, during the preceding stroke was admitted through that passage, will now discharge through it and pass into the exhaust port and up the exhaust pipe, as already described. By the time the piston has reached the middle of its stroke, the valve will have reached the end of its motion on the face of the cylinder, and will begin to move in a contrary direction; so that during the last half of the stroke of the piston, the piston and the valve move in opposite directions. The cavity on the under side of the valve in which the steam turns from the steam or induction port into the eduction or exhaust port, must receive such a width of opening as to allow the exhaust steam to *commence* its escape from one end of the cylinder before steam is admitted to the opposite end; so that if, for instance, the lead of the valve on the induction side be $\frac{1}{8}$ of an inch, [illegible] have a lead of $\frac{1}{4}$ of an inch; or in [illegible] one steam port is taking steam

through ⅛ of an inch, the other must be discharging steam through ¼ of an inch. This is necessary for the free escape of the steam, that it may oppose no load to the progress of the piston.

We are now to show how the motion of the piston is communicated to the driving-wheels, and in what manner the slide-valve Z is moved within the steam-chest so as to regulate the admission of the steam to the cylinder; and to guard against any possible misconception on the part of the student, we will here say that there are two steam-chests, two cylinders, and two valves, together with two entire but similar arrangements for communicating the power exerted by the pistons to the wheels. In a few words, a locomotive is nothing more nor less than *two* non-condensing or high-pressure engines, attached to one boiler on wheels. The figure (11) will admit of the representation of but *one* engine—the cylinder, its valve and piston, being one engine, the other being behind the one shown.

Within the centre of the body of the piston *D* is keyed the rod 9 (called the piston-rod), which passes through a "stuffing-box" in the cover of the cylinder, and is attached at its other end to a "cross-head" E, having a pin or bearing for a connecting-rod. This cross-head is also attached to the "guides," 10, to insure the motion of the piston-rod being in the line of the axis of the cylinder. The connecting-rod takes hold of this pin at one end, and at the other to the "crank-pin," which is fitted into the driving-wheels.

As there are two cylinders and two connecting rods, and necessarily two crank pins, these pins are set at right angles to each other, so that one piston may be exerting its entire force against it, while the other is changing the direction of its motion and is exerting but comparatively little power. The alternate motion of the pistons is thus converted into a continuous circular motion, and it is from this motion that the movement for operating the valves is derived, in the following manner: Four eccentrics, the action of which is the same as that of four short cranks, are fixed on the shaft or axle of the forward driving-wheel "between the wheels." There are two eccentrics to each valve, one being set at such an angle with the crank for that cylinder as to give the proper motion to the valve for a forward motion of the engine, and the other set so as to produce a backward motion. These eccentrics are encircled by straps called "eccentric straps," to each of which is attached a rod called the "eccentric-rod" 12, and these rods are joined together by a slotted segment called the "link" W. This link is raised up or lowered down by means of a bar called the "reverse-bar," which is placed within easy reach of the engineer in the cab.

Now when the link is lowered the eccentric-rod of the forward motion, or go-ahead eccentric, comes in line with the valve stem U, and the valve is operated by that eccentric; but when the link is raised the valve is worked by the backing eccentric; and thus the engine is made to run forwards or backwards at will.

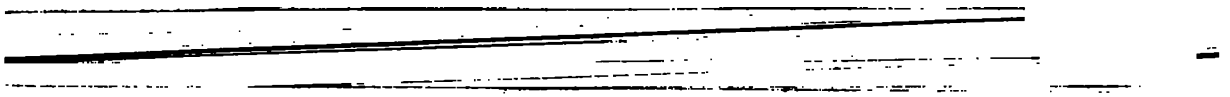
It will now be easy to trace the operation of the steam and the machinery put in motion by its action on the piston. The throttle valve at the mouth of the steam pipe *R*, being opened by the lever, the steam will be admitted to the steam-pipe *SS*, and will pass through it, and through the branch-pipe, into the steam-chest. From here it will find its way into the cylinder through whichever passage may be opened by the valve, and drive the piston to one end of the cylinder, by which time the valve will have opened the other port or passage to admit steam to drive the piston back again.

The motion of the piston will be communicated to the driving-wheel through the piston-rod, the connecting-rod and crank-pin and the motion so transmitted will cause the eccentrics to turn, and by their motion the valves will be operated, by means of the link and valve stem. The driving-wheels as they turn will, by their adhesion to the rails, move along the engine and its load; and the constant recurrence of these motions in the piston, valve, and their connections, will maintain the action necessary to produce the required progressive motion of the engine.

Of the remaining parts of the engine show an additional pair of driving-wheels H, connected with the forward drivers by rods called "side-bars," and turning with them.

The object of this second pair of driving-wheels is to obtain a greater adhesion to the rails than could be obtained with only one pair, and also to relieve the prin-

cipal drivers from the great weight of the engine, which would otherwise come upon them—at least all that portion not supported by the truck wheels. The forward drivers generally have plain rims, while the after ones have flanges on their inner sides, like the truck wheels JJ, in order to keep the engine on the rails. The four forward or truck wheels are combined in a separate frame or truck KL, which turns on a spindle secured to the body of the engine, and is used to facilitate the passage of the engine around curves. There are springs over the bearings of the wheels, to relieve the engine from shocks arising from inequalities passed over on the rails. There are pumps or injectors (not shown in the figure), for supplying the boiler with water as fast as it is evaporated in the production of steam. The boiler is provided with one or more safety-valves to allow for the escape of steam when the pressure exceeds the working limit. There are also a whistle *b*, and a bell *e*, for giving signals, and a sand-box *d*, filled with sand, which is generally used to prevent the drivers from slipping when starting a heavy train; a "head-light" *f*, and pilot *G*. From what has been said, the student will be able to understand the principal construction and operation of locomotive engines, including the operation of the valves and in all; but there are many arrangements of the parts which engines have, however, the



Wheels.	*Ft.*	*In.*
Diameter of main crank-pin bearing.	0	4¼
Length " " " .	0	4¼
Boiler:		
Outside diameter of smallest ring of boiler	4	0
Thickness of boiler plate (steel) . .	0	0⅜
Number of tubes—163.		
Length "	11	3
Outside diameter of tubes	0	2
Length of fire-box inside	8	6
Width " "	2	9¾
Depth " " (sloping)—39–53		
Thickness of fire-box plates (steel), side sheets	0	0¼
" " back sheet	0	$0\frac{5}{16}$
" " crown sheet	0	0⅜
" " flue sheet	0	0½
Square feet of grate surface—24.		
" " heating surface in fire box—112.		
" " heating surface in tubes—933.		
Total square feet of heating surface—1065.		
Tender:		
Number of wheels—8.		
Diameter "	2	6
" tender-axle journals . .	0	3⅛
Length " " . .	0	
Capacity of tank		

Weight:

Weight of engine in working order	75,000 lbs.
" " on driving wheels	51,500 "
" tender, empty	20,500 "

STANDARD AMERICAN FREIGHT LOCOMOTIVE (FIG. 13).

As Designed and Constructed by the Baldwin Locomotive Works, Philadelphia, Pa.

The principal dimensions are as follows:

Cylinders:	*Ft.*	*In.*
Diameter	1	6
Stroke of pistons	2	0
Length of steam ports	1	4
Width " "	0	1¼
" of exhaust ports	0	2½
Travel of valves	0	5⅜
Outside lap of valves	0	0¾
Inside " "	0	0$\frac{1}{32}$
Exhaust nozzles—double, variable.		
Wheels:		
Diameter of driving-wheels	4	6
" " truck wheels	2	6
Distance between centres of front and rear driving-wheels	15	0
Total wheel-base of locomotive . .	22	8
" " " and tender	44	3
Diameter of driving-axle journals .	0	7
Length " " .	0	8
Diameter of main crank-pin bearing	0	4½
Length " "	0	4½

Boiler:		*Ft.*	*In.*
Outside diameter of smallest ring of boiler		4	3
Thickness of boiler-plates (iron)		0	0½
Number of tubes	159		
Length "		11	2¾
Outside diameter of tubes		0	2
Length of fire-box inside		5	5
Width " "		2	11½
Depth " "		5	3½
Thickness of fire-box plates (copper), side, back, and front sheets		0	0½
Thickness of flue-sheet		0	0⅞
" crown-sheet (steel)		0	0⅜
Square feet of grate-surface	16		
" " heating surface in fire-box	103		
" " heating surface in tubes	937		
Total square feet of heating surface	1040		
Tender:			
Numbe ls	8		
Diar		2	4
axle		0	3¼
		0	7

ns.

bs.

Weight:	*Lbs.*
Weight of engine on driving-wheels	68,000
Weight of tender, empty	20,000

CONSOLIDATION LOCOMOTIVES OF THE PHILADELPHIA AND READING RAILROAD.

These engines have the Wootten fire-box, for burning fine coal. It extends laterally over the frames and back pair of driving-wheels, so as to be 8 feet wide inside.

The following are the principal dimensions of these engines:

Cylinders, 20 in. diameter × 24 in. stroke.
Driving-wheels, 50 in. diameter.
Truck-wheels, 30 in. diameter.
Driving-wheel base, 14 ft. 9 in.
Total wheel-base, 22 ft. 10 in.
Fire-box, 114 in. long × 96 in. wide.
Smallest diameter of boiler, 56 in.
197 tubes, 2 in. diameter × 11 ft. 6½ in. long.
Heating surface in tubes, 1,190 sq. ft.
Heating surface in fire-box, 167 sq. ft.
Heating surface, total, 1,357 sq. ft
Grate consists of water-tubes and cast-iron bars.
Driving-wheel journals, 7 × 8 in.
Truck-wheel journals, 5 × 8 in.
Steam-ports, 16 in. × 1¼ in.
Exhaust-ports, 16 in. × 2½ in.
The boiler is fed by two No. 8 Sellers injectors.
Capacity of tank, 2,800 gallons.

Boiler:	*Ft.*	*In.*
Outside diameter of smallest ring of boiler	4	3
Thickness of boiler-plates (iron)	0	0½
Number of tubes	159	
Length "	11	2¾
Outside diameter of tubes	0	2
Length of fire-box inside	5	5
Width " "	2	11½
Depth " "	5	3½
Thickness of fire-box plates (copper), side, back, and front sheets	0	0½
Thickness of flue-sheet	0	0⅞
" crown-sheet (steel)	0	0⅜
Square feet of grate-surface	16	
" " heating surface in fire-box	103	
" " heating surface in tubes	937	
Total square feet of heating surface	1040	
Tender:		
Number of wheels	8	
Diameter "	2	4
" tender axle journals	0	3¼
Length " "	0	7
Capacity of tank	2000 gallons.	
Weight:	*Lbs.*	
Weight of engine in working order	80,000	

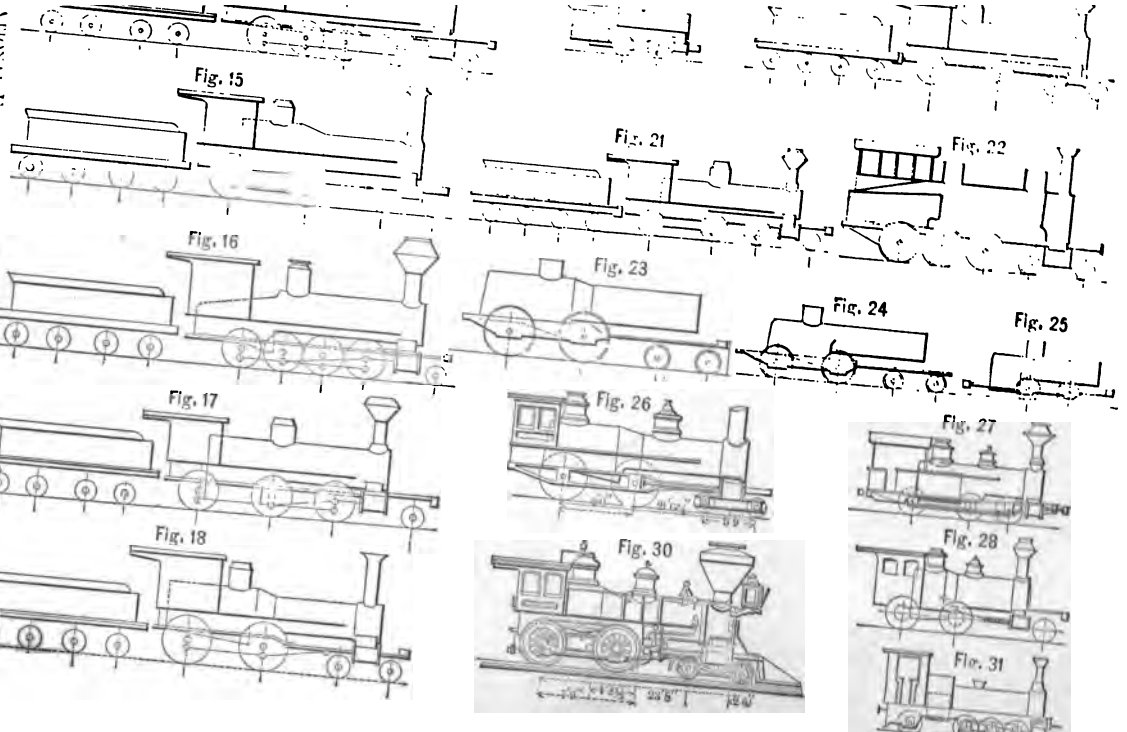
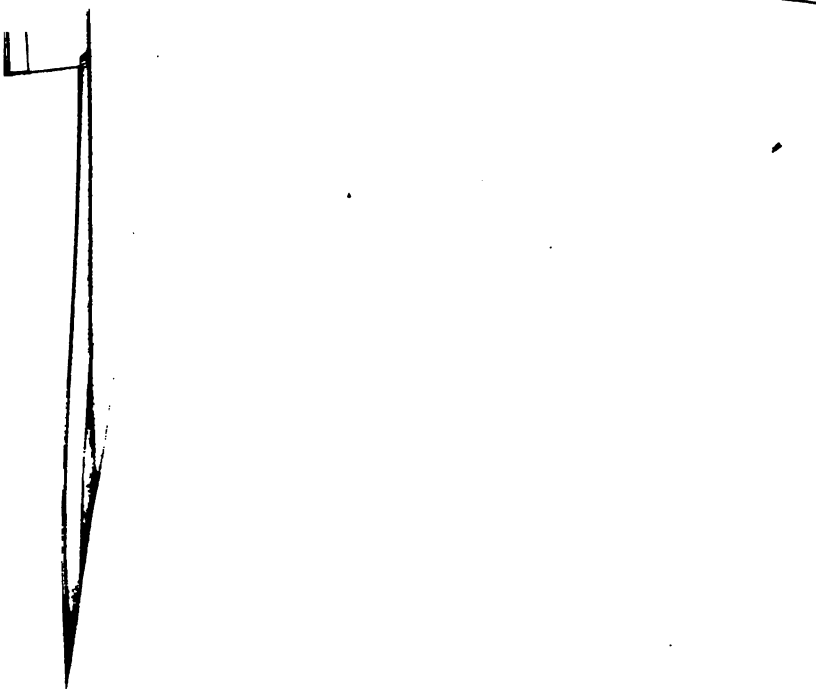
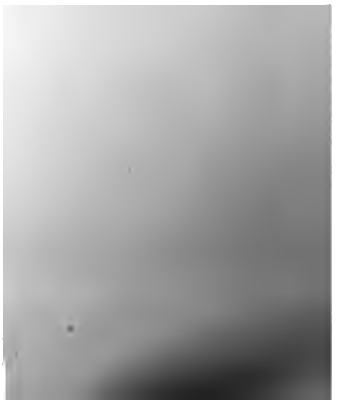


Fig. 15
Fig. 16
Fig. 17
Fig. 18
Fig. 21
Fig. 22
Fig. 23
Fig. 24
Fig. 25
Fig. 26
Fig. 27
Fig. 28
Fig. 30
Fig. 31

No.	REFERENCE NUMBERS OF DIAGRAMS	14	15	16	17	18	19	20	21	22
27	Width of exhaust port	2 1-2 in.	2 1-2 in.	2 1-2 in.	2 1-2 in.	2 1-2 in.	1 1-4 in.	2 in.	2 in.	2 1-2 in.
28	Outside lap of valve	3-4 in.	3-4 in.	3-4 in.	3-4 in.	3-4 in.	7-16 in.	5-8 in.	9-16 in.	3-8 in.
29	Inside " "	1-12 in.	0	0	1-32 in.	1-32 in.	1-32 in.	1-32 in.	1-32 in.	...
30	Travel of valve	5 3-4 in.	5 in.	5 in.	5 3-8 in.	5 3-8 in.	2 1-2 in.	4 1-2 in.	4 1-2 in.	4 1-2 in.
31	Throw of eccentrics	5 in.	5 in.	5 in.	5 in.	5 in.	2 in.	4 1-2 in.	3 1-2 in.	3 3-4 in.
32	Type of valve gear	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link
33	Position of "	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe
	BOILER AND FIREBOX:									
34	Maximum internal diameter of boiler	57 in.	51 1-4 in.	55 3-8 in.	53 in.	50 1-4 in.	24 5-8 in.	43 1-2 in.	39 1-2 in.	50 in.
35	Minimum " " "	53 in.	48 3-4 in.	53 1-2 in.	50 in.	47 1-4 in.	23 3-8 in.	41 1-4 in.	37 1-4 in.	46 in.
36	Height of centre of boiler above rails	6 ft. 4 3-16 in.	6 ft. 2 in.	6 ft. 5 in.	6 ft. 1 1-4 in.	6 ft. 2 1-4 in.	3 ft. 4 1-2 in.	5 ft. 2 in.	4 ft. 9 1-4 in.	6 ft. 5 1-2 in.
37	Length of firebox inside at bottom	9 ft. 10 in.	6 ft. 0 5-8 in.	8 ft. 6 in.	5 ft. 5 in.	8 ft. 6 in.	2 ft. 5 1-4 in.	4 ft. 11 in.	4 ft. 6 1-4 in.	8 ft. 0 in.
38	Width of " " "	2 ft. 9 7-8 in.	2 ft. 10 7-8 in.	2 ft. 10 1-2 in.	2ft. 11 1-2 in.	2 ft. 9 3-4 in.	2 ft. 0 3-4 in.	1 ft. 9 1-2 in.	1 ft. 10 1-2 in.	5 ft. 6 in.
39	Height of firebox crown above grate	38 1-2 in. and 50 in. (k)	58 in. and 62 in. (k)	36 in. and 55 in. (k)	56 1-2 in. & 59 1-2 in. (k)	32 1-2 in and 47 in. (k)	2 ft. 6 in.	3 ft. 11 in.	3 ft. 9 in.	30 ft. & 43 ft. (l)
40	Number of tubes	198	155	188	159	163	43	112	124	198
41	Outside diameter of tubes	2 in.	2 1-4 in.	2 1-2 in.	2 in.	2 in.	1 1-2 in.	2 in.	1 1-2 in.	1 3-4 in.
42	Inside " "	1.782 in.	2.032 in.	2.282 in.	1.782 in.	1.782 in.	1.334 in.	1.782 in.	1.334 in.	1 1-2 in.
43	Length of tubes between tube plates	10 ft. 11 in.	10 ft. 7 in.	12 ft. 10 in.	11 ft. 3-4 in.	11 ft. 2 in.	6 ft. 3 in.	8 ft. 4 1-4 in.	8 ft. 0 1-4 in.	11 ft. 6 in.
44	Boiler material	Iron	Steel	Steel	Iron	Steel	Iron	Iron	Iron	Iron
45	Thickness of boiler plates	1-2 in.	3-16 in.	3-4 in.	1-2 in.	5-8 in.	5-16 in.	3-4 in.	5-8 in.	3-8 in. & 1-2 in.
46	Tube material	Iron	Iron	Iron	Iron	Iron	Iron	Iron	Iron	Iron
47	Thickness of tubes	.109 in.	.109 in.	.109 in.	.109 in.	.109 in.	.083 in.	.109 in.	.083 in.	1-8 in.
48	Firebox material	Steel 3-16in.	Steel 3-16in.	Steel3-16 in.	Copper 3-4 in.	Steel (o)	Steel 1-4 in.	Steel3-16 in.	Steel	Steel
	HEATING SURFACES:									
49	Heating surface of firebox	sq. ft. 112	sq. ft. 106	sq. ft. 92	sq. ft. 103	sq. ft. 112	sq. ft. 24	sq. ft. 72	sq. ft. 60	sq. ft. 86
50	External surface of tubes	1131	971	1159	927	953	106.5	490	391	1042
51	Internal " "	217	271	1057	826	848	93.8	436	347	894
52	Total heating surface with external tube surface	1243.0	1077.0	1251.0	1030.0	1065	130.5	562	451	1128.0
53	Total heating surface with internal tube surface	1119.0	977.0	1149.0	929.0	960.0	117.8	508.0	407.0	980.0
54	Firegrate area	24	18	23 1-4	16	24	5	8.5	8.5	28
55	Flue area through full sectional area of tubes	sq. in. 563.	sq. in. 502.20	sq. in. 563.6	sq. in. 398.9	sq. in. 405.87	sq. in. 60.2	sq. in. 278.88	sq. in. 173.6	sq. in. 349.86
56	Number of internal diameters in length of tube	73.3	62.5	67.5	75.0	75.2	56.1	56.25	72.15	92.9
57	Kxternal tube surface divided by firebox surface	10.10	9.16	12.60	9.00	8.51	4.44	6.06	6.52	12.12
58	Total heating surface divided by firegrate area	51.79	59.83	53.80	64.37	44.37	26.10	66.12	53.05	40.28
59	Firegrate area divided by flue area	6.87	5.61	5.92	5.14	5 51	11.96	4.39	7.05	11.52





No.	REFERENCE NUMBERS OF DIAGRAMS	23	24	25	26	27	28	29	30	31
	WEIGHTS OF ENGINE:									
60	Weight of engine empty	67,500 lb.	36,400 lb.	15,980 lb.	...	27,325 lb.	27,000 lb.	...	54,500 lb.	
61	Weight of engine in working order	71,000 lb.	39,000 lb.	18,900 lb.	...	37,000 lb.	32,000 lb.	...	62,000 lb.	
62	Weight on coupled wheels in working order	47,000 lb.	26,560 lb.	18,900 lb.	...	37,000 lb.	24,000 lb.	abt.24,000 lb	40,000 lb.	
63	Weight empty per square foot of heating surface	61.8	96.3	71.6	...	79.9	58.0	...	56.4	
	MISCELLANEOUS:									
64	Contents of coal tanks	...	...	...	...	1,700 lb.	...	2500 lb.		
65	Contents of water tanks	...	...	217 gals. Eng.	...	427 gals. Eng.	...	666 gals. Eng.		
66	Diameter of blast nozzle	2 in. (x)	2 3-8 in. (x)	1 7-8 in. (y)	3 in.	2 in.	...	2 1-2 in. to 3 in.	2 5-8 in& 2 7-8 in.	
67	Maximum diameter of chimney	15 in.	11 in.	8 in.	44 in.	32 in.	32 in.	30 in.	66 in.	
68	Minimum " "	15 in.	11 in.	8 in.	16 in.	11 in.	11 1-4 in.	11 in.	15 in.	
69	Least sectional area of chimney in square inches	176.71	95.03	50.26	201.06	95.03	99.40	95.03	176.71	
70	Firegrate area divided by least sectional area of chimney	19.67	25.00	16.04	16.44	9.61	9.17	15.15	11.73	
71	Working pressure of steam in pounds per square inch	130 lb.	130 lb.	130 lb.	140 lb.	140 lb.	120 lb.	125 to 150 lb.	120 lb.	
72	Nature of fuel used	Anthracite	Anthracite	or Bit. coal	Anthracite	Bituminous	Bituminous	Bitum's (z)	Wood	
73	Tractive force for each pound of effective pressure per square inch on pistons	103.1	80.66	38.52	111.04	53.78	44	53.78	108.74	30.73
74	Tractive force with an effective pressure on the pistons equal to four-fifths the boiler pressure	10,723	8393.8	4006.1	12,436	6109.4	4224	6453	10,439	
75	Tractive force in previous line expressed in per cent. of adhesion weight	22.81	31.63	21.19	...	16.51	17.60	23.05	26.10	
	TENDER:									
76	Number of wheels in tender	9	8	...	8	...	8	...	8	
77	Diameter of " "	33 in.	24 in.	...	30 in.	...	26 in.	...	30 in.	
78	Material of " "	Chilled castiron	Chilled castiron	...	Chilled castiron	...	Chilled castiron	...	C. I. chilled tyres	
79	Contents of coal space	10,800 lb.	5500 lb.	...	7924 lb.	...	4000 lb.	...	Capacity1cd	
80	Contents of water tanks, Eng. gals.	2900	913	...	1833	...	1000	...	1666	
		23	24	25	26	27	28	29	30	31

Sixty miles an hour, as it strikes the ear, does not seem an impossibility; but if we look at it in all its bearings, and consider that it means *one mile in one minute*, or *sixty miles in sixty consecutive minutes*, it begins to assume proportions that seem insurmountable.

Some of the earliest locomotives ever built have run over a mile a minute, and in one instance a speed of ninety-three miles per hour was maintained for a few miles.

To illustrate more clearly the difficulties in running sixty miles in sixty minutes, the locomotive must be capable at all times of developing *seventy miles per hour*, so as to meet any contingency that may arise. A locomotive at seventy miles an hour passes over one hundred and two feet per second $\left(\frac{70\times22}{15}=102.6\right)$. Two objects near a person, say three feet apart, pass his eye in the thirty-fifth part of a second. When two trains having this speed pass each other, the relative velocity will be two hundred and five feet per second; and if one of the trains were one hundred and two feet long, it would flash by in a single second. To accomplish this, supposing the driving wheels to be six and one-half feet in diameter, and the piston to change its direction in the cylinder ten times in a second, there being two cylinders to every locomotive, and the eccentrics being so adjusted that the exhaust steam discharges alternately, there are twenty discharges of steam per second, at equal intervals, and these twenty exhausts divide a second into twenty equal parts, each puff having a twentieth of a second between it and that

ded. The ordinary locomotive boilers do not eed 1,100 feet of heating surface and 20 square feet of fire grate. In this new locomotive the boiler has about 1,400 square feet of heating surface and about 56 square feet grate surface.

The dimensions of the engine are as follows:

Cylinders, 18 × 24 inches.

Total wheel-base, 21 feet 1 inch.

From centre of driving to centre of trailing-wheels, 8 feet.

Boiler, made of steel, $\frac{7}{16}$ inch thick.

Diameter of boiler at smoke-box end, 52 inches.

198 tubes, 2 inches in diameter × 12 feet 2¾ inches long.

Fire-box, 96½ inches long × 84 inches wide, 51 inches deep in front, and 44 inches back.

Grates, made of water tubes, 1⅞ inches outside diameter × ¼ inch thick, spaced 2⅞ inches from centre to centre, with three bars arranged to pull out.

Truck has a swing bolster and four 36 inch-wheels, with cast-iron centres and steel tires.

Journals of truck axles, 5 × 8 inches.

Steam-ports, 1⅝ × 16 inches.

Exhaust-ports, 3 × 16 inches.

The valve is of the Allen pattern, with ⅞ inch lap.

Cross-heads are made of solid wrought-iron, with brass gibs on slides.

Driving-wheels, 6 feet 6 inches in diameter, with cast-iron centres, having solid spokes and hollow rim.

Tires 3 inches thick.

Driving-axles, made of wrought-iron, with journals $8 \times 9\frac{1}{2}$ inches.

Trailing wheels, 45 inches diameter, with cast-iron centre and steel tires.

Journals of trailing axle, $7\frac{1}{2} \times 8\frac{1}{2}$ inches.

Boiler supplied with two injectors. No pumps are used.

Tender carries 4,000 gallons of water.

Tender-frame made of channel iron.

Tender wheels 36 inches in diameter, with cast-iron centres and steel tires.

Tender axle journals, 5×8 in.

The weight of engine in working order is 85,000 lbs.

Weight on driving-wheels, from 35,000 to 45,000 lbs.

Weight on trailing-wheels from 15,000 to 25,000 lbs.

Weight on truck, 25,000 lbs.

The top and sides are stayed with $\frac{7}{8}$ in. stay-bolts. The boiler has 1,400 square feet of heating surface.

The Bound Brook road is not fitted with water troughs between the tracks, so that the locomotive tender can pick up its water while in motion: thus, larger tenders are needed to convey sufficient water for the through trip.

By dispensing with the coupling rods, and reducing the centrifugal force of the driving wheels, it is evident that the design of the engine is in the right direction for safety and fast running.

The tractive force of each pound of effective pressure per square inch on the pistons which this engine is capable of exerting will be

$$\frac{18^2 \times 24}{78} = 99.68 \text{ pounds.}$$

In running sixty miles per hour, on an ordinary road, which corresponds to about 258 revolutions, or a piston speed of 1,034 feet per minute, and a mean effective pressure of about 35 pounds per square inch, the tractive power exerted will be

$$\frac{18^2 \times 24 \times 35}{78} = 3,489 \text{ pounds}$$

for each piston, and the horse-power for the two cylinders will be

$$HP = \frac{18^2 \times 1,034 \times 35}{33,000} \times 2 = 552.72.$$

To run a train sixty miles in sixty minutes between Philadelphia and New York would not be considered as remarkable, provided the track was always clear; but several large towns, cities, and bridges, some of which have draws, are, however, scattered along the route, necessitating a material reduction of speed in passing them, and thus time is lost, which must be made up by a proportionate increase in speed on those parts of the roadway which are clear and unobstructed. This increased speed must be as great, at times, as *seventy miles* an hour, as before stated.

On Friday, May 14, 1880, I received an invitation from Messrs. Burnham, Parry, Williams & Co., to make a trip on a train to be drawn by their "new departure locomotive, No. 5,000," the 5,000th of their build (Philadelphia and Reading Railroad Company's No. 507), from Ninth and Green streets to Jersey City, over

The signal to go ahead was given at precisely 11:16 a. m., and on account of Ninth street being more or less obstructed by teams crossing, 9½ minutes were consumed in reaching Wayne Station, distance 4.3 miles, rate of speed per hour, 27.15 miles.

Wayne Station to Jenkintown, distance 5.8 miles, time 6.75 minutes, rate of speed 51 miles per hour.

Jenkintown to Yardley, distance 20 miles, time 19 minutes, rate of speed 63 miles per hour.

Yardley to Trenton Junction, distance 2 miles, time 2¼ minutes, rate of speed 53.3 miles per hour.

Trenton Junction to Bound Brook, distance 27.1 miles, time 25¾ minutes, rate of speed 63 miles per hour.

Bound Brook to Elizabeth, distance 20.7 miles, time 20¾ minutes, rate of speed 60 miles per hour.

Elizabeth to Jersey City, distance 11½ miles, time 14 minutes, rate of speed 49.3 miles per hour.

Total time from Ninth and Green streets, Philadelphia, to Jersey City, 89.4 miles, 98 minutes, rate of speed 54.73 miles per hour.

THE RETURN.

On the return trip one car was added, making the total load 168 tons.

Left Jersey City at 2.07 Philadelphia time, reached Elizabeth at 2.21½, distance 11½ miles, time 14½ minutes, rate of speed 47½ miles per hour.

Elizabeth to Bound Brook, distance 20.7 miles, time 19 minutes, rate of speed 65.3 miles per hour.

Bound Brook to Trenton Junction, distance 27.1 miles, time 26.8 minutes, rate of speed 60.6 miles per hour.

Trenton Junction to Yardley, distance 2 miles, time 2⅓ minutes, rate of speed 53 miles per hour.

Yardley to Jenkintown, distance 20 miles, time 20.8 minutes, rate of speed 57.6 miles per hour.

Jenkintown to Wayne Junction, distance 5.8 miles, time 8 minutes, rate of speed 43.5 miles per hour.

Wayne Junction to Ninth and Green streets, distance 4.3 miles, time 8½ minutes, rate of speed 30.3 miles per hour.

Total time from Jersey City to Ninth and Green streets, Philadelphia, 100 minutes, distance 89.4 miles, rate of speed 53.6 miles per hour.

The best performance during the trip was in running the 2.8 miles from Willitt to Langhorne, part of which distance is an ascending grade of 16 feet per mile, in two minutes, being at the rate of *eighty-one miles per hour*.

A careful examination of all the bearings at the end of each trip showed them to be perfectly cool, which is something extraordinary for a new engine, running 90 miles without stopping.

To show the speed this engine is capable of performing, on a former trial she ran 13.8 miles in 10½ minutes, or at the rate of *seventy-eight and eighty-five hundreths* of a mile per hour.

Some idea of the steaming capacity of the boiler may be had from the fact that a No. 9 Sellers injector,

which will throw 2,000 gallons of water per hour, will not keep her supplied.

The water consumed in the 98 minutes' run to Jersey City was about 3,300 gallons, and on the return trip about 3,600 gallons, or about 34½ gallons, or 288 pounds per minute.

Comparing this time with the fast time made by the 7.35 a. m. going east, and the 3.30 p. m. coming west, on the Pennsylvania Railroad from Germantown Junction to Jersey City and return, we have as follows:

Pennsylvania Railroad.—Germantown Junction to Jersey City, distance 84.2 miles, time 106 minutes, rate of speed 47.7 miles per hour.

Reading Railroad.—Wayne Junction to Jersey City, distance 85.1 miles, time 88½ minutes, rate of speed 57.6 miles per hour.

Jersey City to Germantown Junction, distance 84.2 miles, time 103 minutes, rate of speed 49 miles per hour.

Jersey City to Wayne Junction, distance 85.1 miles, time 91½ minutes, rate of speed 55.7 miles per hour.

Being seventeen per cent. less time going east and twelve per cent. coming west than that now made by the Pennsylvania Railroad.

The advantage of large diameter for driving wheels is in the reduction of the number of revolutions per mile. In the Baldwin engine the revolutions per mile are $\frac{1680}{6.5}=258$, and those of the Pennsylvania Railroad, with a 5½ foot wheel, $\frac{1680}{5.5}=305$, an increase of

$\frac{305-258\times100}{305}=15.4$ per cent., and their engines being coupled, this additional number of revolutions adds to the risk by increasing the momentum of the parallel rods and tending to separate them.

It must not be supposed that 80 miles an hour is the limit of speed which a railway train may attain. Speed is a question of power and resistance, and velocities greater than 80 miles an hour, which is about 7,000 feet per minute, are in use in various kinds of machinery, to wit: fan-blowers, circular saws, etc.

The writer believes that before the expiration of five years, with the present active rivalry, passengers will be set down in New York in one hour's time from this city.

The mean average of all the English railways is 46.2 miles per hour; French, 37.5 miles per hour; German, 40 miles per hour; and American, 37 miles per hour; the English being 20 per cent. faster than in this country.

With them, 6½ foot driving wheels are quite as common as 5½ foot wheels are with us; in fact, some of the fast lines have eight and nine feet, and one line had ten feet diameter.

Engines with one pair of drivers are not new in this country. The *Ironsides*, built by M. W. Baldwin in 1832, had but one pair of drivers, 4½ feet in diameter. Mr. William Pettit ran her on the Philadelphia and Germantown Railroad at the rate of 62 miles per hour. Dr. Patterson, of the University of Virginia, and Mr. Franklin Peale, were on the engine, and timed its working on that occasion.

In 1849 Edward S. Norris, of Schenectady, built for the then Utica and Schenectady Railroad the *Lightning*, Crampton, with 16 inch cylinders, 22 inch stroke, and a single pair of 7 foot wheels, which ran at the rate of 60 miles an hour in the year 1850, but it only worked a short time.

Messrs. M. W. Baldwin & Co., in August, 1849, delivered to the Vermont Central Railroad an engine, the *Governor Paine*, with 17 inch cylinders, 20 inch stroke, and a pair of 6½ foot driving wheels, and subsequently sent three Crampton engines, of smaller dimensions, to the Pennsylvania Central Railroad in September, 1849.

Norris Brothers made seven engines for the Camden and Amboy Railroad, each with a single pair of 8 foot driving wheels, and a 6 wheeled truck. The first of these, with 13 inch cylinders and 34 inch stroke, was sent from the makers' shops, April 17, 1849. The next of the class had 13×38 inch cylinders, and were delivered December, 1849. The last of the series, delivered in April, 1853, had 14 inch cylinders and a 38 inch stroke. The 13 inch cylinders weighed, empty, 40,754 pounds, and loaded, 49,253 pounds. Of the weight loaded, 18,496 pounds, or about 8¼ tons, were on the driving wheels, with about 13¾ tons on the truck, making [illegible] tons in all. These engines had [illegible] diameter, with plates but $\frac{5}{16}$ inch

[illegible] cylinder engines,
[illegible]ke, and coupled 7

foot driving wheels, for the New York and Erie Railroad (new Erie Railway).

In the year 1849 Ross Winans, of Baltimore, built a single locomotive for the Boston and Worcester Railroad. It was for an experiment in coal-burning, and constructed to burn anthracite coal. This locomotive was named the *Carroll of Carrollton.* It had one pair of 7 foot driving wheels, and was intended for very high speed. It had two small steam cylinders placed on the sides of the boiler, over the bearings of the driving axle, by which the weight on the drivers could be varied from three to twelve tons.

The 7 foot drivers were cast with chilled rims and were of extremely light pattern; in fact they became broken after running six weeks. These were replaced with a set of imported wrought-iron wheels, the first of the kind brought to this country.

The speed of the engine, under favorable circumstances, was one mile in sixty seconds. It was run between Albany and Boston, and the train consisted of from seven to eight cars, and made a mile a minute with ease. The engineer, J. H. Jackman, says: "Since I run her in 1849, I have traveled many thousand miles on locomotives, and have seen some high speeds made, still I have never seen the locomotive that could lay right down to it and out-run the *Carroll of Carrollton.* When I run her we made many stops, and therefore could not make better time than locomotives having smaller driving wheels. But give me fifty or sixty miles on a clear run, and I could out-run a

thunder-storm if it was going our way. In those days we had no air-brakes, and to run at such high rates of speed sometimes became dangerous. I remember one instance, in the night time, of rounding a curve at about sixty miles per hour, when a danger signal met my view. I shut off steam and whistled down brakes, but they did not seem to check me. I whistled again; still the speed kept up. I gave the third signal for brakes, and then reversed my engine, saying to her, 'Do your duty, my beauty, or in twenty seconds it is good-by to railroading.' We came to a stand-still eighty rods from a train on the main track, having run one mile and a quarter from the place where I first discovered the red light. A locomotive engineer, to avoid trouble, must take time by the forelock—in other words, must anticipate possibilities."

Not over a dozen and a half of single engines have been made in the United States. Smaller wheels have been substituted for nearly all of these engines, from the fact that all the large-wheeled engines had small boilers, and with a single pair of driving wheels the adhesion was in all cases insufficient for the want of a proper distribution of the weight excess, as in the case of the *Carroll of Carrollton*, and, as before stated, the adhesion weight could be varied between three and twelve tons.

The present Baldwin has a similar arrangement, as before described, also the great advantage of a large boiler with ample heating and grate surface.

The Great Western Railway of England has seven

foot gauge, and was the fastest road in the world until a few years since, and its express ran regularly from Paddington (London) to Bristol, 118¼ miles, in precisely two hours, being at the rate of *fifty-nine miles* per hour.

CHAPTER XII.

RECENT IMPROVEMENTS IN THE LOCOMOTIVE.

THE last meeting of the Master Mechanics' Association was largely devoted to the consideration of the report of its Committee on the Construction of Locomotive Engines. The committee appointed to gather facts concerning improvements, or the remedy of well known defects in the construction of locomotives, report that in only two or three directions have valuable modifications been perfected. The committee turned its attention particularly to the consideration of questions relating to economy of fuel, locomotive trucks, spark-arresters or consumers, and the operation of consolidation locomotives. The committee report that they are in possession of no information that promises any real improvement in the form of construction of boilers, or in valves, or in machinery for working them.

In other respects, however, valuable improvements have been made, and chief among these is a spark-arrester, which, having been put to test by actual use, seems to have secured very important results. In the language of the report, it "has secured immunity from setting fires, not only arresting but perfectly consuming the sparks and smoke; also preventing the falling of fine dust from the train, improving the steaming

qualities of the engine, and resulting in the saving of fuel." The only ones described in the report are those in use on the Fitchburg Railroad, and on the Camden and Atlantic. Mr. Hill, the inventor of the one in use on the latter road, describes his invention as follows:

"A deflecting plate is arranged in the smoke-box near the flue-sheet, so as to cover the top flues, and extending downward toward the bottom of the smoke-box. A steel-wire netting is placed in front of said deflecting-plate to confine the circulating sparks from passing to the open air, or coming in contact with the exhaust steam. A straight pipe without any obstruction is used for a smoke-stack; the sparks after falling to the bottom of the smoke-box come in contact with an injector operated with a bell-crank and rod, under the control of the engineer. The power used to operate the injector is a small portion of exhaust steam, which can not be noticed by an expert. From the mouth of the injector a pipe is so arranged as to convey the sparks and steam to the fire-box. The moist steam used, being of a low temperature, readily combines with the smoke and gases, thereby supplying a deficiency needed to ignite them. Instead of admitting cold air into the furnace, warm, moist steam is admitted. The netting, to insure against clogging, is provided with a striker, under control of the fireman, and operated from the cab of the engine."

In regard to the operation of consolidation engines, the report presents an elaborate array of facts; although it acknowledges that they are not yet com-

Another thing considered by this committee was the value of injectors; submitting a large number of facts, including a statistical table setting forth the observations with regard to the saving of fuel by the use of this appendage, furnished by Mr. E. T. Jeffrey, of the Illinois Central Railroad. The engine used by Mr. Jeffrey was run eight trips of 128 miles each, using her pumps exclusively, and then the same number of trips over the same section of road, using the injector exclusively. The engine burned 6342 pounds less of coal with the injector than with the pump; but nearly nine hours more time was spent in switching at way stations when the pump was used, which reduces the saving in coal to 4342 pounds. A chief objection to the use of the injector, as at present constructed, seems to be the difficulty in regulating so as to feed the proper quantity of water at all times. The committee consider that the following facts have been settled by the experiments which they have recorded:

1. A good injector properly attached is as reliable as a pump for feeding a locomotive boiler, provided the water in the tank is not heated to more than 110 degrees Fahrenheit.

2. A small saving in fuel is effected by using an injector; the boiler pressure is steadier, and the boiler is subjected to fewer changes of temperature.

3. A pump will feed only when the engine is moving, but an injector will feed the boiler when the engine is in motion, or at rest.

The report and the discussions thereon show that a

CHAPTER XIII.

STRENGTH OF BOILERS.*

THE pressure in a steam boiler or other containing vessel tends to force the same into a circular form, if it does not possess that form; and if it does, the pressure has a tendency to sustain it in that form. Hence, the strongest form for a boiler is a circle, and any departure from that shape makes itself manifest by the necessity of stays. While the pressure acts from the center radially out to the circumference on an indefinite number of radial lines, the mathematics of the strength of the shell supposes that the pressure acts as

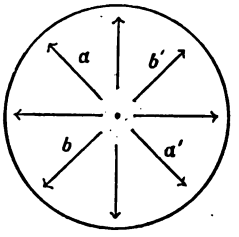


Fig. 32.

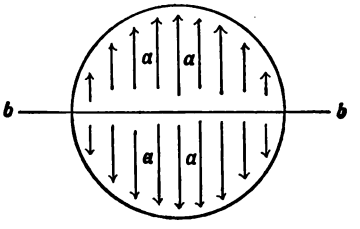
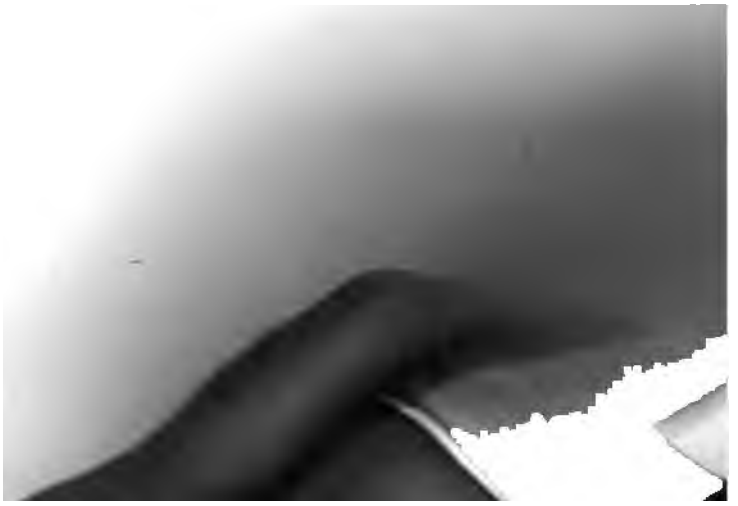


Fig. 33.

the arrows a, a, a, a, in Fig. 33, that is, tending to lift the top from the bottom. In Fig. 32 the pressure represented by arrow a is resisted by arrow a', and similarly arrow b and b' resist each other, and as each

* Smith.

locomotive is probably, all things considered, the most perfect engine yet made by man. Certainly it is the one engine which has concentrated upon its construction the most thought and ingenuity.



the strength of the weakest portion, which, of course, comes under the principle that the strength of any structure is equal only to its weakest part, 56 % of 31,250 = 17,500, which is the product of the length of our section (1 in) multiplied by the diameter, say 48 inches, multiplied by the pressure per square inch necessary to burst the boiler. We have, therefore, to find the pressure per square inch necessary to burst the boiler, only to divide 17,500 by the diameter (the length being 1 inch or unity). This gives us nearly 365ths, which, divided again by our factor of safety, we will take as 6 (or the working pressure= to $\frac{1}{6}$ the bursting pressure), and we obtain 60 nearly, as the proper working pressure, all of which tends to show that there are few locomotives in the United States that are not carrying more pressure than they ought to, or would be allowed to, if there was a law regulating the same.

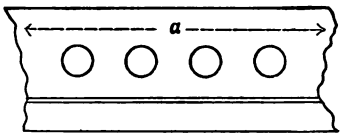


Fig. 34.

The strength of a joint, like Fig. 34, through the rivet holes, may be found by taking the length *a*, less the diameter of one hole multiplied by the number of holes. This leaves the length of solid iron between the holes, which, multiplied by the thickness and by the strength of a sectional inch, and from 15% to 20% deducted from the result, for injury done the iron by the punch, leaves the probable strength of metal between the holes. A staggered or double-riveted joint,

plus the equal area, *c*, *c*, and the whole multiplied by the detensive strength of the sheet, which is about 50,000 pounds per square inch. In designing a joint, the piece *a*, Fig. 36, the shearing strength of the rivets and the strength between the holes should be as nearly equal as possible, to make as strong a joint as is possible. The joint shown in Fig. 38 has a welt piece, *a*, added, and is much used in locomotive work. It does not add as much strength as is commonly accredited to it. The line of rivets *d* and *f*, Fig. 37, are commonly spaced twice as far as the middle one *e*, and therefore present only half the shearing strength of rivets that line *e* does, and hence if rupture were to take place it would occur first through either *d* or *f*, if it were not for the stronger joint *e*. Therefore, after the internal pressure exceeds the strength of joint *d* or *f*, they are no longer of use, as rupture is alone prevented by the superior strength of the joint *e*. The welt strengthens the joint, ...ply because it puts the rivet *g*, Fig. 38, into dou... ...hear, that is, the rivet must be sheared through ... *h* and *i*, and therefore presents double re... ...ce. The part of the plate in front of the rivet

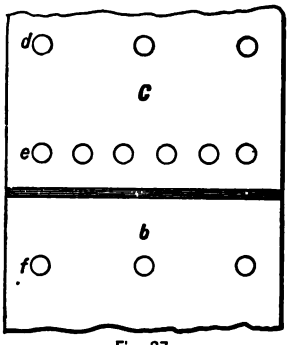


Fig. 37.

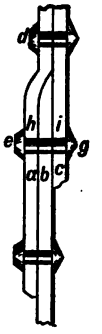


Fig. 38.

must be proportionally increased to meet the increased resistance, and the pitch of the holes increased as much as possible and still retain a tight joint. A combination of this joint and the staggered riveted joint would make the strongest possible longitudinal joint, as it would give the greatest amount of metal between the holes, and also present the rivet in double sheet. Fig. 39 shows a mode of making a joint by which the strength might be made equal to that of the solid sheet. The distance between the holes, by

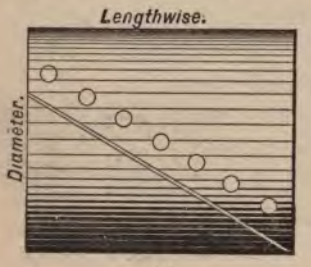


Fig. 39.

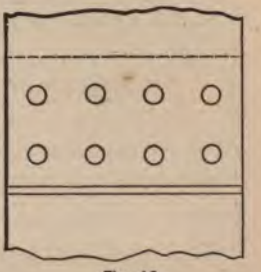


Fig. 40.

making the joint long enough, might be made equal to the width of the sheet, or in excess of it, for injury done in punching. The joint shown in Fig. 40 is not strengthened by the second row of rivets, barring the grip due to contraction of the extra rivets, as the strength [illegible] between either row is the same, as is [illegible] number of rivet[illegible] and the joint is a[illegible]ugh one r[illegible] the [illegible] I [illegible] sidering [illegible] strength [illegible]

g or forging, and fastening of crow feet or stay lugs shell and heads. It is not a rare thing to find crow et forged of flat bar iron strong enough to resist with rfect safety a working strain of 40,000 lbs. fastened the shell of a boiler with two 5/8″ rivets, and these ceiving the stress at an angle of 45°.

I think that a neat and strong crow foot can be opped or rolled with two, three and even four webs receive rivets; these can be heated and bent to any rm desired. This method would certainly establish a iiform standard as to strength, and would materially duce the cost of manufacture in the shop, besides e advantage in having room for extra rivets.

The stays should be of the best material hammered om the merchant bar. Holes in the ends rimmed to e. The stay pins should be turned and drilled to ceive annealed wire guard pins. Where threads are ed the parting of rod on which thread is cut should enlarged, so that the bottom of thread will have the me sectional area as the body of stay rod. Continous head stays should have steel expansion collars to low for expansion of tubes. Collars must be of steel. very stay rod should be so arranged that it can be moved from the boiler and examined and tested, and herever pitting and wasting are discovered the stay ld be condemned, and a perfect one inserted.

reful experiments with locomotives have proved brick arch in the fire box, as well as a baffle plate he smoke box, are both very economical appli- They save coal and prevent throwing fire. It

work is well done. The riveting over of the ends of the tubes is quite generally practiced, and when well done makes a very strong joint, but those who are familiar with this kind of work know that in many cases the ends of the tubes are frayed out and split, and until the 'thumb tool' is brought to bear, the job has a very unpromising look. Such work yields readily to the action of the heated gases, and after a time the riveting, or beading, fractures and crumbles off, and very little strength remains. This fraying and cracking is sometimes attributed to a want of proper annealing of the ends of the tubes, but it is quite as often the result of unskilled workmanship. We have seen it so often that we are never sure that it is well done."

"Another method of fastening tubes into the tube sheet, and one that, so far as we have investigated, works well, the test being upon boilers in use, is to djust the tubes so that they shall project slightly be- nd the tube sheet. Roll them in with the Dudgeon pander, and then, with one of the tools shown in s. 42 and 43, flare, or further expand the projecting . Figs. 44 and 45 show the above tools in cross n."

ttle explanation of the manner of using them is ry. After the tubes are rolled in, either of the ols can be used for expanding the ends. Some tool with two points of contact, and others e with three. The tool is inserted into the tube and driven with a hammer until the

"In order to ascertain what the holding power of tubes set in this manner would be, we arranged with H. B. Beach & Sons, boiler makers of this city, to prepare for us two (2) specimens for test. They were tubes three inches external diameter rolled into 3/8 inch plate, and expanded as described above. These specimens were handed to Mr. Charles B. Richards, Consulting Engineer at Colt's Armory, in this city, with the request that he submit them to the required test. The following is Mr. Richards' report:

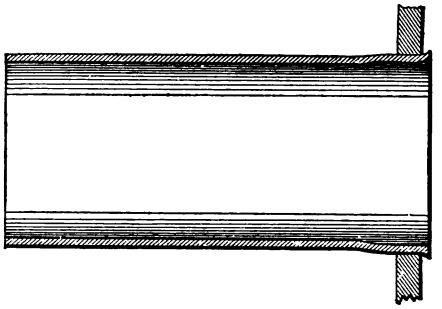


Fig. 46.

"'*Report by the Colt's Patent Fire Arms Manufacturing Company, of tests of the holding strength of two boiler tubes expanded into iron plates. The samples were received October 8th, from Mr. J. M. Allen, and were tested for him.*

"'The external diameter of the body of the tube was 3 inches, and the thickness 0.109 of an inch. One end of the tube was fastened in an iron plate ⅞ of an inch thick and 6 inches square. The tube was fastened

served stress which first produced yielding was 20,500 lbs. and 19,000 lbs. To ascertain what the holding power of the tubes in an ordinary tubular boiler 48″ in diameter would be, we have to multiply the holding power of one tube by the number of tubes.

"Fig. 47 represents the tube head of a 48″ boiler.

"We will assume the lowest result of the experiments, viz., 19,000 lbs., as the holding power of one tube. In the above tube head there are 47 tubes, and 47× 19,000=893,000 lbs., the holding power of all the tubes. It will be seen that these tubes are in the lower half of the boiler. The upper half is supposed to be thoroughly braced and stayed by stay-rods running back on the body sheets of the boiler. Consequently the tubes furnish the support for the lower half of the tube head. (We are not now taking into account the support derived from the joining of the flange of the head to the body of the boiler.) To ascertain the actual resistance of internal steam pressure to be overcome and provided for, we first ascertain the area of the head in inches, and multiply it by the internal pressure per square inch. The area in square inches in a tube head 48 inches in diameter is 1,809.6 square inches. But we have already stated that the upper half is supported by braces and stays running back on to the body sheets of the

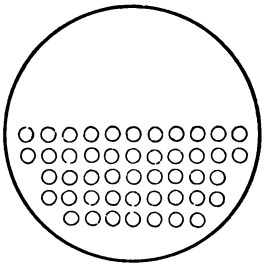


FIG. 47.

by punching a row of holes close together (Fig. 49), completely around the piece to be taken out; the bottom edge of the dome is then flanged to fit the top of the boiler. Now, unless the iron is of the best quality, and the workman well skilled, there is great danger of the flange cracking, and in time the chemical action of the steam and water will cause a serious leak on the sides where the flange fits upon the shell of the boiler.

We remember seeing several cases where this took place, and particularly one, where there was a crack of nearly six inches in length; the only remedy then being to put on a patch over it, thus impairing the strength and looks of the boiler. A better plan is the following: By referring to Fig. 48, the reader will readily understand the principle, and it will be observed that the sheet forming the shell of the boiler is also flanged as well as the dome, thereby adding greatly to the strength. We remember one man who was so much absorbed in this plan that he claimed to restore the shell of the boiler to its former strength, by applying the dome in the manner shown in the cut. We believe this to be an exaggeration; but, however, we get a good strong job, and a durable one. It is the practice in some parts of Europe to put a stout wrought-iron ring round the hole under the flange of the dome. Now, while we admit that there are other means of fastening the dome to the shell of the

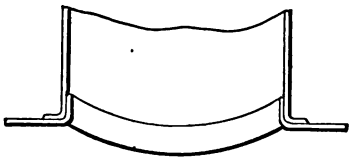


FIG. 48.

We remember seeing two men work two or three days in getting out the steam-pipes, and finally broke off the flange, and spoilt the section so that it had to be replaced by a new one. If the designs had been properly made there would have been no trouble, and the work done in half a day or less.

So much for the application of the dome. We will now consider the manner of applying braces to the dome by a reference to Fig. 50, where A represents a

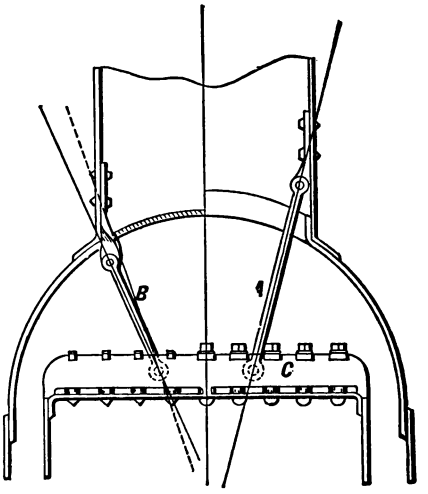


FIG. 50.

brace properly applied, and B represents a fault very common where too many privileges are allowed to the workmen.

We have had occasion several times in our exper-

generally bolted to crown-bar. The most trouble that we have experienced in connection with the crown-bars has been from the hole around the bolts so stripping entirely. Such a bolt is represented in Fig. 51, where the bolt is simply riveted on the under side of the crown-sheet (there were no threads on these bolts), and frequently in riveting the heads become fractured, consequently when the strain comes upon them they snap off, thereby causing great trouble. Another plan used by some builders is represented by Fig. 52, where the hole in the crown-sheet is tapped and the bolt is screwed down from the top, with a nut placed upon the end that projects through the crown-sheet. It is a very easy matter to put these bolts in when the boiler is building, but when the boiler has been running awhile, and it becomes necessary to replace any of these bolts, it is quite a difficult operation. It is a difficult task to operate a wrench inside of the boiler, and we have, time and again, heard men (as the boys say) swear a page or two by note, and pronounce all sorts of imprecations upon the designer, while replacing some of these bolts.

Fig. 51.

Fig. 52.

[illegible] good if proper care [illegible] but in our experience [illegible] be screwed up [illegible] is raised upon [illegible] to move quite

easily, owing to the fact that the bolt is elongated by expansion.

We have not space to describe the many ways of fastening crown-bars: as a matter of course some of them are good and some worthless. But we will describe a plan which we have thoroughly tested for a number of years, and is now in use, believing it to be the cheapest, and we will also say the best way of applying crown-bar bolts.

By an inspection of Fig. 53, the reader will observe that we have a plan differing from those previously described. We have a die to fit the bolt-machine or swage-block, with a hole through it to admit ⅞ in. round iron. The top of this die is bored, tapering to the depth of 1 inch, and reamed with a taper reamer (shown by Fig. 54), with the collar A removed, making the hole 1⅛ in. diameter at the top, thereby giving a taper of ¼ in. to 1 in. of length. The bolts must be heated as nearly as possible to the same degree, then placed in the die and the round head of 1½ in. diameter formed. The threads are to be cut in a bolt-cutter, which is all that is required to finish them. To prepare the crown-sheet for their insertion, we place the collar A, Fig. 54, upon the reamer, and ream one of the holes previously punched with a ⅞ in.

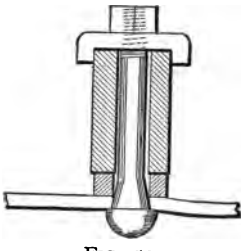


FIG. 53.

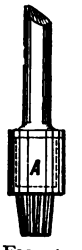


FIG. 54

generally bolted to crow-feet. The most trouble that we have experienced in connection with the crown-bars has been from the leak around the bolts or stripping entirely. Such a bolt is represented in Fig. 51, where the bolt is simply riveted on the under side of the crown-sheet (there were no threads on these bolts), and frequently in riveting the heads become fractured, consequently when the strain comes upon them they snap off, thereby causing great trouble. Another plan used by some builders is represented by Fig. 52, where the hole in the crown-sheet is tapped and the bolt is screwed down from the top, with a nut placed upon the end that projects through the crown-sheet. It is a very easy matter to put these bolts in when the boiler is building, but when the boiler has been running awhile, and it becomes necessary to replace any of these bolts, it is quite a difficult operation. It is a difficult task to operate a wrench inside of the boiler, and we have, time and again, heard men (as the boys say) swear a page or two by note, and pronounce all sorts of imprecations upon the designer, while replacing some of these bolts.

FIG. 51.

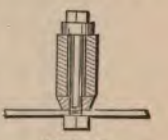


FIG. 52.

The nuts upon the end are very good if proper care was observed in screwing them up, but in our experience we have found that the nuts may be screwed up tight when cold, and yet when steam is r[illegible] the boiler these nuts will be found[illegible]

punch, and allow the bolt to go up to within 1/8 in. of the head. The object of the collar A is to act as a gauge, running the reamer down until the face of this collar touches the sheet. This collar is faced off and properly gauged at the time it is made, and there are four grooves filed across the face to clear away the chips which would otherwise lodge under it while running.

It will readily be seen that by this process we get the holes of a uniform size. If the reader will look at Fig. 53, we will describe the application. It will be observed that there is a collar of 3/4 in. thick between the bars and the sheet, while a piece of flat iron with the ends turned down so as to form a lip is placed across the top.

When the bolt is put in place, and the nut tightened, a few smart blows with a heavy hammer will bring it up to the head. We remark here that the ends of the bolts inside of the boiler should never be allowed to project through the nuts, as the threads will become corroded, and when the attempt is made to unscrew them they will invariably be broken.

The same rule holds good for all bolts inside of the boiler and smoke-arch. This method of applying crown-bar bolts possesses several important advantages, as follows: By using the rough iron bolt, the skin of the iron not being broken, they possess superior strength, and using the taper, the strain is taken off the head. They are easily removed, and we never knew one to break; therefore, for cheapness and dura-

bility, we think this plan cannot be excelled. We would add a few remarks in regard to the management of boilers.

Whenever there is a boiler explosion, there is no end to the people expressing their surprise at the catastrophe, but it is equally surprising to us that there are not more explosions from the careless manner in which steam-boilers are handled. We were shown a boiler a few days since, and were informed that it had run between three and four years without being washed out, and that there was a cart-load of dirt taken from it. No doubt that there were any amount of complaints about that engine consuming so much coal with so little effect.

We advocate the plan of leaving out the three lowest rows of tubes, considering them of no use, as they are nearly always stopped up, and in their stead place a good-sized hand hole in the front end, whereby a scraper can be inserted and the dirt loosened; then, with a hose, wash it out. If neglected, the space left by the removal of the tubes leaves so much more space to fill up with mud before it will interfere with the heating surface.

A common practice among engineers is to pull down the lever of the safety-valve, or screw down the pop-valve, if it is a possible thing, until the gauge shows 130 lbs. per square inch, the limit of pressure allowed to be carried on the majority of roads. We remember a case where a certain engineer made a brag of how much work he could do with 80 lbs. of

steam, and finally the gauge on his engine was taken off and tested, and it was found that he had been carrying 140 lbs. per square inch. It is our opinion that a steel spring such as are used in steam gauges and on safety-valves cannot be trusted; and in view of this fact, no gauge should be allowed to run over three months without testing. It is a small operation, and pays well in the end.

In firing up a boiler when cold, the fire should be started very slow, and allow the iron sufficient time to heat uniformly. Many a boiler has been ruined through allowing some ignorant person to fire up under it.

CHAPTER XIV.

SLIDE VALVES.

THIS is a branch of the subject deserving the special attention of the engineer. Its importance in regard to the economical working of the steam engine cannot be overestimated.

The slide valve ordinarily used in locomotive engines, and the manner of its operation, is well known to nearly every practical mechanic and engineer. It will be remembered that the operations of admitting the fresh steam and releasing the waste steam are alternately performed by the same valve and the same motion. The valve being made to slide backwards and forwards upon the face of the ports, opens and closes the several passages in their turn. The two extreme ones, called the steam ports, communicate with each end of the cylinder. The middle one is called the exhaust port, and its corresponding passage terminates in a pipe open to the atmosphere. Steam is admitted freely into the steam chest from the boiler, and the valve is made of sufficient length to cover all the ports, when it is placed in the centre of the stroke. When it is in this position no steam can enter the cylinder, but as the valve moves on one of the ports opens, the arrangement of the valve gearing being

s effect upon the consumption of fuel. If from
ıuse the valve should open to admit steam for a
ɜtroke before the preceding stroke is finished, it
too soon, and an unnecessary resistance to the
is produced. If, on the other hand, the valve
ɨ delay its opening until the piston had begun
turn, it opens too late, because then the steam
fill uselessly the space left vacant, and hence a
of steam and loss of power. As far then as the
sion of steam is concerned, it is a necessary con-
that the *steam* ports should open neither before
ter, but at the precise moment when the stroke
ences. Some engineers recommend giving the
"lead" as it is termed, that is to say, setting it
to open a little before the end of the stroke, but
n open question whether the slightest advantage
ıed by so doing to a greater extent than is nec-
to compensate for any slackness or lost motion
ɜ valve gearing or for their expansion when
ɨ by the steam, and $\frac{1}{16}$ of an inch is quite suffi-
ɨn a well-constructed engine. It is also an open
on whether it would not be better to bring the
to a state of rest by the "compression" of the
st steam than by means of any lead to the steam
at all. Now the valve shown in Fig. 55 satifies
onditions for the *admission* of the steam; it
exactly at the right time; the steam begins to
as the piston begins to move, as it follows it
y and effectively throughout the stroke. What-
ɨme the piston takes for its journey, the steam is

will be better understood by noting what would happen without it. If there were no lap the opening for steam would be represented by O D (see Fig. 57), and the

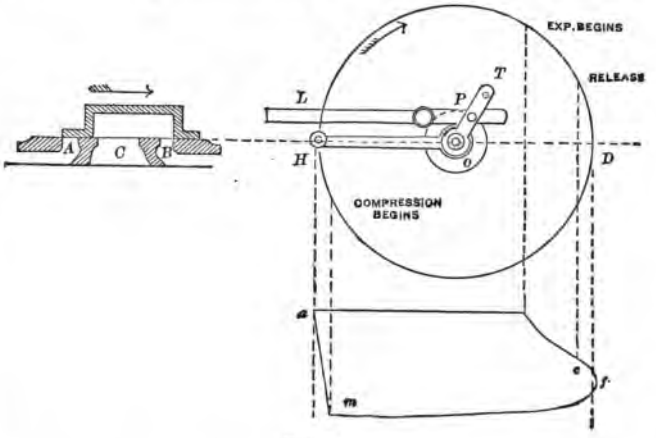


FIG. 57.

result would be that the steam port could only be perfectly closed at the precise instant when the valve was in the middle of its stroke and moving most rapidly. From what has been said it is apparent that a valve of this kind (one without lap) is unsuitable for an engine, the better plan being that the steam should be compressed or cushioned on one side of the piston, so as to assist in bringing it to a state of rest, and that the driving pressure on the opposite side should be relieved by opening a passage to the exhaust or releasing the steam just before the stroke terminates. This prevents the violent jerk and strain which would come

end of first dotted line, A is closed, expansion begins, the pressure falls, and we have the expansion line B C. At the point marked "release" the valve is moved so far to the left as to open a passage from A to C, and the release of the steam (exhaust) begins. The pressure falls from C to F, and continues very low till the point marked "compression" is reached, when B closes and the steam in the corresponding end of the cylinder is "cushioned" so as to increase its pressure, the pencil rising from M to A when the double stroke has been completed. The object and effect of putting "lap" upon a valve are two-fold: 1st, to give a free release to the exhaust steam, and 2d to produce a fixed amount of expansion.

The "lead," of which mention has been made, is outside lead, that is, it relates to the *admission* of the steam; but, of course, "lead" can be given to the exhaust side of the valve, in which case it is called *inside* lead. The four principal points in the valve motion are: 1st, the admission of the steam; 2d, the cut-off; 3d, the release or exhaust, and 4th, the compression or cushioning of the steam behind the piston.

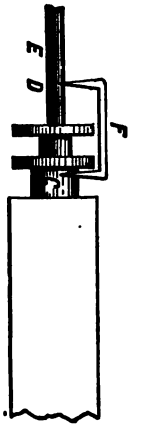
PRACTICAL METHOD OF SETTING THE VALVES OF A LOCOMOTIVE.*

Before entering into a practical consideration of the subject before us, it may be proper to state the object of the writer in treating on the subject of Slide Valves, from the fact that there has been so much pre-

*Lyne.

rections, and from the point C, as before, describe the arc E, also put a permanent mark at E, care being taken to make these points correspond with the points of the tram. These points will show the position of valve when the cover is put on the steam chest. We must now satisfy ourselves that the reach rod is the right length, by throwing the lever in the forward notch. Set the links plumb and measure from top of the link block to top of the slot in link, throw the lever in the back notch, set the links plumb and measure from bottom of block to bottom of slot in link; these measurements will show if the links hang high or low.

FIG. 58.



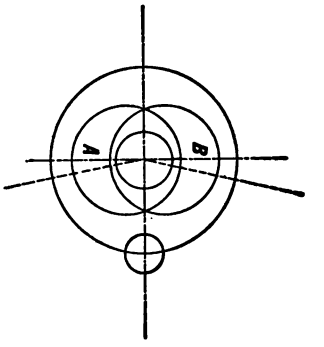


FIG. 59.

Practice has demonstrated that it is better to hang the links ⅛ in. high, as the wear is all down on the different parts. Care should be taken to take these measurements on both links, as it often occurs,

even on new work, that one link will hang higher than the other for various reasons, sometimes owing to a depression in one frame. If this is found to be the case, and the variation is but slight, the lowest side of the tumbling shaft may be raised by putting a liner under the bearing. If the arms should need any setting, this should be done before altering the length of the reach rod, as these alterations would conflict with each other. After the links are proved to hang alike, the height may then be adjusted by lengthening or shortening the reach rod, so that they hang according to previous directions.

The next thing in order will be to set the eccentrics, which may be done by commencing with the right hand side of the engine.

Place the crank on the forward center, then examine the marks on the straps, in order to see which is the forward and the back motion; as some builders put the forward motion eccentric next to the box, and *vice versa*, hence the necessity for this precaution. Practically, it is better to put the back motion next to the box, because the forward motion is then easier to get at, which is a great advantage, particularly when an eccentric slips while on the road, and the forward motion is the most important. We have often heard engineers curse the man who puts the forward motion next to the box. If the back motion is to be placed next to the box, move the eccentric up to within ½ of the box, and roll it around so that the belly throw, comes directly under the axle, as in Fig.

below, and the back motion above the parallel line. This point being taken, we proceed likewise with the other three points, marking them in the same manner.

After finishing the four points in the forward, we proceed to take the same for the back motion, in this manner: Throw the lever in the back motion, and move the engine ahead until the center point on the wheel has passed the point of the tram B about 6 in., then move back carefully until the point fits the tram, and mark the valve stem, as in the forward motion, only the longest part of the arc above the parallel line, (see cut), and so in their order, take the four centers in the back motion. Having taken all the eight points, we now examine the lines to see if the valves are square. With a pair of dividers from the point B take the distance to the nearest point, forward motion, and then place the point of the dividers in the point E, and see if the distance is the same to the nearest line for same motion. If it is, the valve is square, but if not, the

valves are now squared, and the next step is to give them the required lead, which is understood to be the amount that the valve must stand open when the crank is on the dead center. Some master mechanics proportion the amount of lead, so that when the lever is placed in the center notch the valve will have $\frac{1}{16}$ in. lead, which we believe to be a very good plan, for no definite rule can be adopted, as the rods of different engines are of different lengths, and the shorter the rod, the faster the lead will increase. In the case before us we will say $\frac{1}{16}$ in. lead is required at full stroke. On the points B and E, with the dividers, set off $\frac{1}{16}$ in. outside these points, by describing short arcs shown in the cut. Commencing with the right side, place the crank on the forward center with the lever in the forward motion. Slack the set screws in the forward motion eccentric, and roll it towards the crank indicated by the dotted line in Fig. 59, until the point of the tram F, Fig. 58, fits the small lead arc just outside the point B, and tighten the set screws in the eccentric. Now, without moving the engine, throw the lever in the back motion, slack the back motion eccentric, and roll it towards the crank until the same lead arc outside the point B corresponds with the point of the tram F, as for the forward motion. Then tighten the set screws in eccentric.

The engine should be moved over these points to see that they are not affected by lost motion, and very likely the forward motion will have to be readjusted, owing to the fact that rolling one eccentric throws the other out.

In the same manner set the left side and prove it. The valves are now square and have the required lead, but we must ascertain if they will cut off square in each of the notches; therefore, we place a square on the guide, and draw a short mark corresponding to the end of the crosshead when the crank is on the center, which is called the traveled point. Throw the lever in the 10 in. notch, that being used more than the others generally, and hold the tram *F* in position, moving the engine ahead until the point accurately fits into the point *B*. Great care must be taken in testing these points as the crosshead may move some distance without showing much on the valve stem. Measure from the front travel, point to the edge of crosshead, and mark it on the cylinder, or steam chest near the front end, so as to remember it; and in the same manner test all the other points in the forward motion, marking them in the same manner. If, after taking all the points we find that they agree, the valves are right.

But it may happen, and does generally, that there will be a variation caused by the links being worn, etc. For example, we find on the right side that the crosshead will travel 10½ in. from the front travel point, and only 10 in. from the back. We here find that the cut-off takes place too quick on the back end; therefore, to equalize this, we are obliged to shorten the eccentric rods a trifle to cut off square. This, of course, throws the valves out of square in the full stroke notch, but practically, it is found to be the best way to remedy this evil. We may shorten the back

direct to the crank shaft eccentric rods, reversing the engine, and the variable steam expansion is produced through it, by shifting up and down in the link, the "sliding block" of the valve rod or rocker arm. In the shifting link the link itself is shifted up and down on the block, to reverse the engine and to vary the steam admission and release.

Without entering fully into the elaborate series of diagrams and investigations which are necessary for a thorough study of link motions, the two systems of link motions may be shown by simple comparative diagrams and descriptions, making the subject readily comprehended in a general way, advantageously to those who may not have become familiar with it.

The diagram Fig. 62 is an illustration of the stationary link-motion, and Fig. 63 of the shifting link-motion.

In Fig. 63, A is the center of the crank and eccentric shaft of a steam engine; $A\,B$, and $A\,B'$, are, respectively, the crank positions at the commencement of the forward and back strokes of the piston. C, and C' are the fore and back eccentrics, which have their respective centers at a and a' when the crank pin is at B, and at a'' and a''' when the crank is at B'.

The fore and back eccentric rods are, respectively, at D, and D', when the crank is at B, and at D'' and D''', when the crank is at B'. E, is the link "open" and "coupled behind," at b and b', to the eccentric rods D and D', and supported at its center c, by the sustaining link F, on the transverse rock shaft d. The

as in Fig. 62, and the same literal references are used, in order to aid in comparison of the two systems of link-motion.

The principal distinction in the features of the operation of the two systems is, that in the stationary link the valve has unvarying lead and linear advance; while in the shifting link the valve's lead and angular advance varies with every change of the position of the link.

The diagram shows the sliding block G, fixed on the end of the valve rod I, at "mid gear" with the link E. The link and eccentric rod joints are in the position b and b' shown in full lines, when the crank is at B, and when the crank is at B' they are at the positions b'' b'''; so that the horizontal distance $b\ b''$ or $b'\ b'''$ is equal to the change in position of the valve and link at those two positions of the crank.

The horizontal motion of the link, due to the eccentrics, is least at the center of the link, at which point it is equal to twice the linear advance of the eccentrics, or the distance $b\ b''$.

The travel of the valve when in full gear, either front or back, is equal to the full throw of the eccentric moving it;—that is, when the link is open at the end to admit the block to move so as to bring the valve rod in line with the fore end of the eccentric rod.

The varying lead of the valve, produced by shifting the link, may be seen by the diagram. The full [illegible] with the crank [illegible] stroke.

If now the link be shifted down so as to bring the valve in full gear forward, the connecting point b, of the fore eccentric rod and link, will fall at b_4, and the valve be drawn back towards A, a distance equal to the horizontal distance of point b_4 from the dotted circle $b\ b'$ (central at A); thus lessening the lead of the valve by that distance, in changing from mid gear to full gear.

By constructing larger scale diagrams, the varying lead due to shifting the link, may readily be found in a similar way.

The motion of the valve by the stationary and the shifting links and double eccentrics, is substantially the same as that from a single eccentric of variable throw and advance, when the valve gearing is properly proportioned and suspended.

line *a d*. The valve drawing is cut out at the line *f e*, and placed on the line representing the valve-seat.

The laps and lead are laid off (from the pin C, the valve rod running directly from the eccentric to valve) *a b* from center of circles, *a*. The line *b c* is erected perpendicular to center line F C, and through where it cuts eccentric circle at *c* a line is drawn, as *a* B. This line is the center line of eccentric, and the angle C *a* B —the angle formed by eccentric and crank *c*. This angle is constant in whatever position the crank-pin may be.

Place the valve, Fig. 65, on the seat, so that line *d a* coincides with line *c b*, and you have position of valve when crank is on center. As the crank moves, in direction of arrow, from C, the valve moves from right to left, and back again, till right-hand edge of valve comes to edge of port, *z*. The steam is now cut off, and, to find position of crank-pin, notice that the line *a d* on valve cuts the center line, F C, at *b*, which, extended down to small circle, cuts it at *e*. The line *a e* D is now evidently the centre line of eccentric. Taking the distance, B C, in a pair of compasses, and measuring back from D, we find the point A, which is the position of the crank-pin when steam is cut off. The valve now continues to move from left to right till edge of exhaust cavity, *g*, comes to edge of port, *h*, when the exhaust commences. The center line on valve *d a* now cuts line F C at *a;* this, extended down, cuts eccentric circle at *m*. A line, *a m j* G, now represents the center line of eccentric; laying off the distance, BC,

er the high pressure employed in locomotive en-
:s. The contrivance is thus described in a paper
an improved piston for steam engines: "Three
ırate grooves, each ¼ inch wide, ¼ inch apart, and
ıch deep, are turned in the circumference of the
ɔn, and these grooves are fitted with elastic packing
s. These rings, which may be of brass, steel, or
, are drawn of a suitable section to fit the grooves

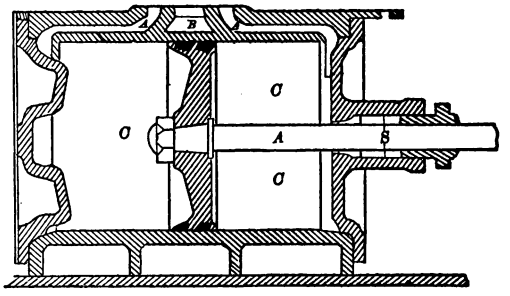


FIG. 68.

ıe piston, and are bent in rollers to the proper cur-
re, the diameter of the circle to which they are
: being about one-tenth larger than the cylinder.
y are placed in the grooves in a compressed state,
along with the body of the piston are thus put
the cylinder, care being taken to block the steam
. The rings are therefore forced outwards by their
elasticity, which is found quite sufficient to keep
ı steam-tight." Of course the rings are put on so
ɔ break joint. One object in the construction of
particular piston has been to reduce as much as
ible the amount of rubbing surface. It is a maxim

CHAPTER XVIII.

INJECTORS.

THE injector was invented by M. Giffard, of France. The invention of the injector for supplying feed-water to the boiler of an engine is principally remarkable as presenting an illustration of the direct conversion of heat into work. Before describing the apparatus it will be necessary to explain the meaning of the term "induced current."

Looking back historically it appears that in 1719 Hawksbee, the inventor of a double cylinder air-pump, showed that when a current of air was sent through a small box—entering by an opening at one side near the top and escaping by a corresponding opening at the opposite side—the effect was to rarefy the air within the box rather than to compress it. It is an old experiment to suck up and drive a jet of spray out of a bottle by blowing through a horizontal tube with a contracted nozzle whose end is placed just over a vertical tube dipping into water contained in the bottle. The current of air passing over the open mouth of the vertical tube carries away some of the air from inside the tube, whereby the water rises to the top and is dispersed in a jet of spray.

According to theoretical definitions the particles of gases repel one another and have no coherent action

corresponds to A B in the elementary diagram, and by turning the wheel marked "water regulator" the tinted sliding tube is brought up or down, so as to regulate the supply of water which is sucked up by the inducing action of the steam. There is here, therefore, precisely the apparatus already described, together with the mechanical means for regulating the supply of steam and the supply of water.

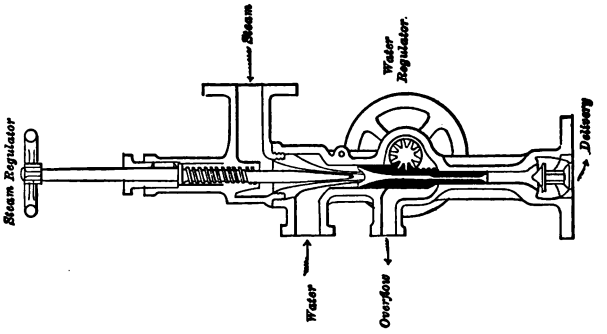


FIG. 70.

At one end of the injector is a valve opening outwards, leading to the flanged and marked "delivery," which is in direct communication with the boiler. This valve is shown open in the figure, but it is closed by the pressure in the boiler when the injector is not at work.

Looking again at Fig. 69, which is intended to show the action in its most simple form, we may point out that M. Giffard discovered that a jet of mixed steam and water, issuing from E under the circumstances above stated, is competent to overpower and drive

be changed. The motion of heat would be diminished, but the onward motion would remain unimpaired. This liquid line would be moving at such a high velocity that it would pierce any jet of water coming towards it from the boiler, very much as if it were a steel wire forcing its way through the mass. We know of no source of cold competent to produce this result, but what really happens is the same in character though less in degree. The steam, liquefied at E, retains to some extent the higher velocity which it possessed as steam, and on the whole the aggregate energy of the water globules flowing onward at E is greater than that of the water jet coming towards them from D. The latter jet is overpowered and driven back, and a quantity of water from the cistern at A is continally forced into the boiler.

As to the velocities with which we have to deal, it appears that if the steam had an actual pressure of six atmospheres the water would issue at a velocity of about 101 feet per second, and the steam at a velocity of about 1,800 feet per second.

Referring again to Fig. 70, it will be seen that a pipe marked "overflow" leads out from the centre of the instrument; this pipe communicates with a small chamber in the central channel just below the level of the junction, and is intended to allow the escape of any [redacted]water. When the supply of steam is properly [redacted]o the amount of water sucked into the in[redacted]o overflow takes place, whereas an access [redacted] steam will at once give rise to a discharge

the admission of steam and water, are clearly designated in the figure, the latter being provided with a suction chamber to steady the flow. A fixed receiving-tube, through which the principal jet of steam passes, is regulated by the position of the interior conical spindle. The annular jet of steam combines with water in the combining-chamber, and the concentrated jet is forced through a delivery-tube, and the check-valve shown, to the boiler. The combining-tube forms part of the piston, which fits freely into the case, and the smaller end of combining-tube slides freely also in the end of delivery-tube. The pressure of the water is on one side of the piston, and the other side is in communication with the jet issuing from combining-tube through an opening inside of delivery-tube. If the water-supply be too great, a portion escapes through an opening and accumulating in the surrounding chamber, forces the piston and combining-tube towards the receiving-tube, and contracts the annular space between the two latter, so that the water-supply is reduced. If the water-supply be insufficient, a partial vacuum will be produced in the chamber, and the piston moved to admit more water. In this manner the supply of water is automatically adjusted to suit all the requirements.

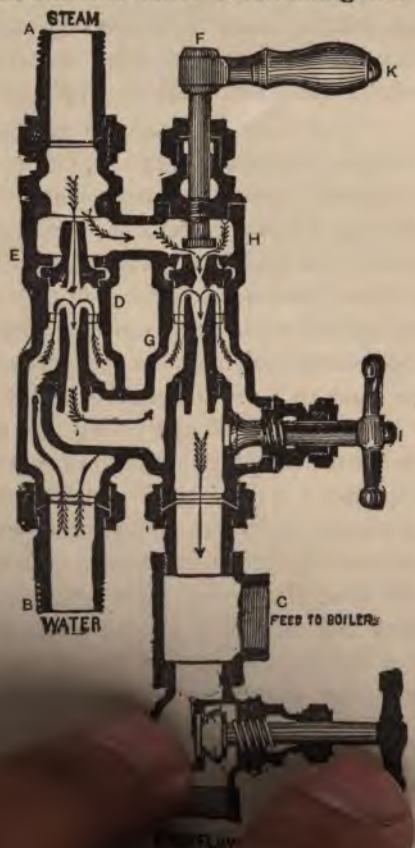
The description thus far is common to all the Sellers' self-regulating injectors. In the "Injector of 1876," the central spindle shown in the receiving and combining-tubes is secured to an operating-spindle, and has a small bore throughout its length, which

injector, and not relieved again till the lever is at the other extreme, as above explained. The instrument can be located in any convenient position on the locomotive above the water-level, as it is considered advantageous to have the injector lift its supply of water.

THE HANCOCK INSPIRATOR.

The Hancock Inspirator, Fig. 72, differs in some important respects from the instruments commonly classed under the head of injectors. It consists essentially of a lifting-jet and lifting-nozzle, combined with a forcing-jet and force-nozzle or injector, steam being admitted to both of these nozzles whenever the inspirator is in operation, to deliver the supply-water to the force-nozzle, and to force it through this nozzle into the boiler. Although both the lifting and force-nozzles are fixed, their proportion one to the other is such that the inspirator requires no adjustment for changes in steam-pressure or water-supply, the waste-valve being kept closed while the instrument is in operation, except at the time of starting. The sectional view of the stationary inspirator, Fig. 72, will serve to explain the action of the instrument. In this figure, A is the steam-supply pipe, connected to the steam-space of the boiler; B is the water-supply pipe; and C is the feed-pipe, to which is connected an overflow or waste-pipe with waste-valve, these latter connections not being shown in the figure. D is the lifting-jet, E the lifting-nozzle, G the forcing-jet, and H the force-nozzle. This latter nozzle is somewhat analogous to the combining-tube of an ordinary injector. F and I are stop-valves,

the first controlling the admission of steam to
forcing-jet, and the latter determining the cours



The actio
pla

in connection with a description of the manipulation required to start the instrument. In the figure, the inspirator is represented in operation; but when it is not working, a steam-valve in the pipe A, not shown, is closed, as is also the valve F, while the valve I and the waste-valve are open. Opening the valve in the steam-supply pipe A, steam is admitted to the lifting-jet D, drawing water through the supply-pipe B, and discharging it through the lifting-nozzle E, valve I, waste-valve, and overflow-pipe. As soon as water issues from the overflow-wipe, the valve I is to be closed, when the supply-water will pass through the force-nozzle H, and will escape at the overflow. The valve F is then to be opened, by moving the lever K one-quarter turn, and the waste-valve is to be closed, when the water lifted and delivered to the force-nozzle H will be forced into the boiler by the steam issuing from the forcing-jet G. If the water supply is to be varied, this can be effected by partially closing a valve in the supply-pipe B without throttling the admission of steam; or both the steam and water may be throttled if desired. In practice, however, the delivery is varied by throttling the water-supply. Whatever changes of adjustment are made, whether of steam or water-supply valves, within the capacity of the inspirator, the instrument will continue in operation with the waste-valve closed. In this respect the inspirator differs materially from fixed-nozzle injectors, which cannot be operated with the waste closed, under the conditions recited above.

pose that the pressure of steam has been gradually increasing, which likewise increases the velocity of the water in the combining-tube, until it is driven through faster than it can be supplied, and air will be drawn in at the overflow; but this is prevented by the small check-valve. Whenever this occurs, we are generally warned by a peculiar sound coming from the injector.

This will go on until the amount of water is not sufficient to condense the steam, and be at a less temperature than 212° Fahr., which will cause the formation of steam, which is very light, although, with its high velocity, it has not sufficient power to overcome the boiler pressure, and must, consequently, pass out at the overflow in the form of a very wet steam, so to speak.

From the above it will be seen that although the velocity of the mixture of a temperature above 212° Fahr., or when the formation of steam takes place, is much higher than that of a mixture in which this formation does not take place, the power of the former is much less than that of the latter, "because the total actual energy is proportional to its *weight* multiplied by the square of its *velocity*."

To illustrate this in a very simple way, let the reader procure two wooden balls of the same size, one of hard and heavy, and the other of a soft and light wood.

Either of these balls will float on the surface of a body of water, and it will require some force to sink it; but take them up, and throw the heavy one, for

By carefully considering the foregoing, it is obvious that the amount of water that the injector throws must increase in proportion to the amount of steam used, when the temperature of the feed-water is raised.

It is obvious that it requires a greater amount of water to condense the steam, and be at a lower temperature than say 195° Fahr., than it would if the temperature of the feed-water were lower.

From what we have already stated, it will be seen that when the amount of water is large in proportion to the amount of steam, the velocity of the mixture

FIG. 73—THE RUE LITTLE GIANT INJECTOR.

also diminishes. This also applies to the above, when the temperature of the feed-water is raised.

With a certian pressure of steam and temperature of feed-water, the power of the mixture may be just sufficient to overcome the boiler pressure; whereas, if the temperature of the feed-water is still increased, it will require a proportional amount of water to con-

perature of the mixture below, say 195°, and you may not have given it all the water that the stream would safely carry into the boiler.

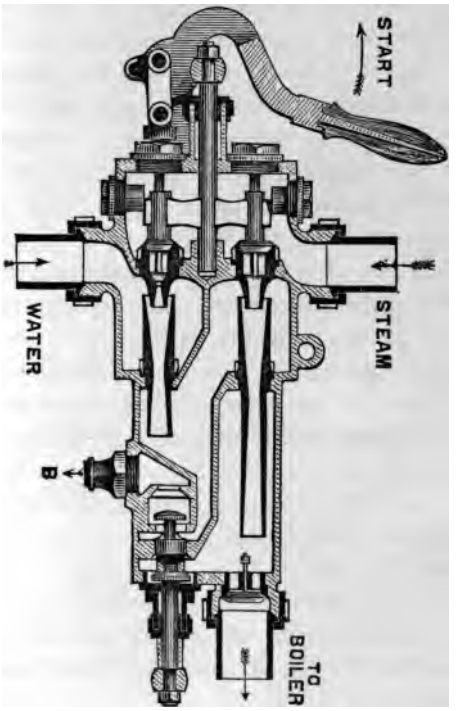


FIG. 74.—THE KORTING UNIVERSAL INJECTOR.

THE KORTING UNIVERSAL INJECTOR.

As will be observed by Fig. 74, the instrument is a combination of two steam-jet apparatus; the first one proportioned for lifting and delivering the water

Fixing the Injector.

The injector should, preferably, be fixed horizontal, in which case it will drain itself when not in operation. The pipe should not be smaller than the corresponding size of couplings. The dirt-stop should always be attached where the water is not perfectly clear. There should be a steam stop valve, and a main check valve on boiler. If water flows to the injector, it is necessary to have a stop valve in the water pipe.

Before connecting the injector, have the steam pipe well blown out with steam to clear it of scale and dirt. Do not omit to attend to this, as the nozzle openings are small, and if clogged with red lead or dirt, will interfere with, or stop the action of the injector.

Manipulation.

If the injector has to draw the water, open with handle A, half-way first, till water is discharged through the starting cock B, then open full.

This stop need be of so short duration, that a continuous moderately slow movement will accomplish the required result; so that the instructions for manipulation would read: To start, open with handle A; to stop, shut with handle A. To regulate the quantity of water to a minimum, throttle the water in suction pipe, but keep steam turned on full all the time. Manufactured by Schutte & Goehring, steam jet engi- Philadelphia.

THE KEYSTONE INJECTOR,

ured by E. Tracy, Philadelphia, Pennsyl

same internal diameter, to correspond with the injector coupling. Attach the steam pipe to highest part of boiler, and as short as possible, to obtain dry steam; but in no case make attachments to pipes supplying an engine, pump, etc., as it causes a variation in the steam pressure. Place an ordinary globe valve on steam pipe, a valve or water cock on water-pipe. (There is no necessity for an extra check valve on feed

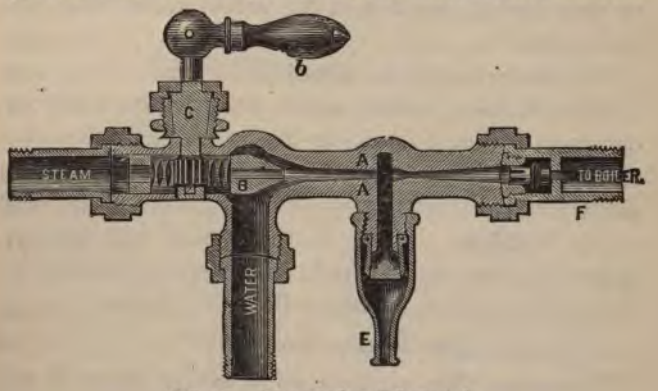


FIG. 75.—Non-suction Injector, A.

pipe near the injector, as there is one in the swivel marked to boiler).

Use no washers or packing, as all joints are ground. Be particular, and remove all scale, cuttings and dirt from pipes, and see they are in perfect working order before connecting.

Method of Working Class "A."

First. Open the steam valve to let out any condensed steam there may be in the pipe, and close it

The Friedmann Injector, on the contrary, with the double waterway, before described, with fixed nozzles, and no movable parts to get out of order, and having no *cam motion, no sliding or rolling levers, and no ground joints or packing* to require frequent adjustment, delivers the water with a steady, uninterrupted stream that no amount of jarring or disturbing influences can break or confuse, while the water-supply lasts, or steam is kept up.

These injectors are lifting and non-lifting, as shown in the Figures 77 and 78.

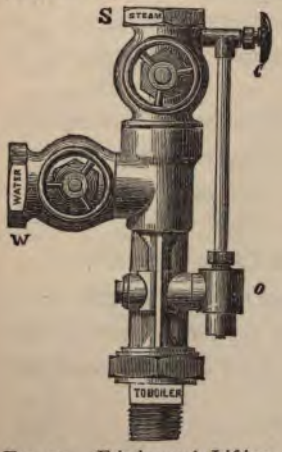


FIG. 77.—Friedmann's Lifting Injector.

Fig. 78.—Friedmann's Non-Lifting Injector.

Special attention is called to the important fact that by a recent improvement in the lifting injectors without increasing their cost or impairing their capacity to supply the boiler, they are enabled to lift water from the unprecedented depth of 25 to 28 feet if required.

Every injector is supplied with an overflow valve, which prevents air or dirt from entering the boiler.

Method of Working Lifting Injector.

Be sure the water valve or cock W is open; then

1st. Open the small jet valve J, with low pressure full, with high pressure partly, until the water flows out of the waterflow at O.

2d. As soon as the water appears at the overflow, open the main steam valve S gradually, and close the small jet valve.

Should water still be discharged from the overflow, as may be the case where the steam pressure is low, reduce gradually the water-supply by the valve W until the discharge ceases.

To stop, close the main steam valve. This injector may also be used as a non-lifting where a head of water is available. While the injector is inactive the steam valve should be kept closed.

Method of Working Non-

To start, 1st. Open the

the condensed water

overflow O, and

pears.

2d. Op

3d.

is w

fore reaching the foot of an unfavorable grade. On long levels and descending grades one injector can be kept working constantly. There should be plenty of water in the boiler before reaching a roadside or terminal station. The furnace door should be kept open as little as possible, as the entrance of the cold air through it contracts the tube sheets, and is sometimes the cause of them leaking. If the engine has a variable blast it is a good plan to open it full when firing, and to immediately contract it very much so as to recover the fire quickly.

The cylinders and valves require to be oiled at about every fifteen or twenty miles of the run. If the ports of the throttle-valve are of the same area as the steam pipe, it is found best to keep the throttle partially closed, as when the pressure is rather less than in the boiler the engine is not so apt to prime. The proper opening for the throttle of any engine can soon be determined by observation. In going through covered bridges or station houses the dampers should be closed, and the draft otherwise checked to guard against fire.

The boiler should be blown out at intervals of a week or more—depending very much on the purity of the water used. When a scale deposits on the tubes and crown sheet, a little coal oil (refined) will help to remove it.

The frequent use of the sand box has the effect to rapidly wear away the tires of the wheels, and therefore should only be used when it cannot be dispensed with.

CHAPTER XX.

KEYING UP LOCOMOTIVE SIDE AND MAIN RODS.*

WHEN it is necessary to key up a main rod, the first thing to do is to take it down, after placing the engine on the center on that side. It would be well to ascertain now if the travel slots in the guides are correctly located. These slots are for the purpose of preventing the cross-head from forming a shoulder on the guides, and they do this by the cross-head traveling half the width of the slot past its inside edge, if the rod is of the right length. Their province is not, as many engineers think, to lead off the oil forced to the end of the guides by the cross-head. To ascertain if they are correctly located, pinch the cross-head to each end of the guides (after the main rod is down) till the piston-head strikes the cylinder head. Then make a mark even with the end of the cross-head on the guides. If these marks are equally distant from the travel slots, they (the slots) are correctly located and can thereafter be used to key the length of the rod too. The rod being down, the pins should be calipered across their horizontal diameter when the engine is on the center, because the pin wears smaller across its horizontal diameter when it is on the top or

* Smith.

Perform the same operation on each end of the rod; put it up and drive the keys to the marks made on them, and then try the length of the rod by pinching the engine past the centers, when, if the cross-head travels an equal distance past the edges of the travel slots in the guides, the rod is of the correct length. If not, its length should be altered (by inserting or taking out liners, as the case may be) till correct when tested by the travel slots, if they are correct.

It is obvious that the rod must be just right when keyed by this plan. The brasses should always be "brass and brass," as they will run much longer. After taking down the side rods, the wheel centers should be trammed and equalized by the wedges, if they are not correct. The wedges should be up snug when keying the side rods. If there is much lost motion in the side rods, the back pins will be found to be behind when the tram is placed on the pin centers. They should, therefore, be slipped till the tram will drop into the pin centers. This can best be effected by taking the weight off from the back wheels with a couple of jacks under the foot-board. The boxes may be reduced to the pins the same as the main rod, leaving them "brass and brass."

The front end of rod may be put up, the joint line of brasses coinciding with center of oil hole in strap as for main rod. Then put up the back end, shifting the boxes in the strap with the two keys in the back end till the rod can be shaken with both hands. This plan first reduces the brasses to the pin, leaving them loose enough when keyed, "brass and brass."

into the fire-box. If the engine cannot be replaced without the help of another engine, the side and main rods should come down to prevent them from being sprung. If the engine is still on her wheels it will generally be found that she can be got back on the track more easily the way she came off. In case of a broken side-rod, disconnect the broken rod and the opposite side-rod also. This is all that is necessary. The necessity for taking down the opposite rod is that if only the broken rod is removed and the pin on that side is on either quarter, the pin on the opposite side being on the center cannot start the back drivers through its side-rod, should the forward drivers slip in starting; the result being that the back drivers, not being compelled to slip with the forward ones, would remain nearly stationary, the front pin would pass the center, shortening the distance between the pins, and the rod would bend or the pin break, necessarily.

If the main rod breaks, disconnect it; block the cross-head at the back end, disconnect the valve stem and tie it to the hand rail if it has a joint, and then go ahead. It would be as well, in connection with the above, to pull the valve clear back so as to open the front port, or cover both ports with the valve, jamming the gland on the stem by screwing up one side only.

The plan frequently adopted by engineers after taking down the main rod is to place the piston at the back end of the cylinder, open the front port, and jam the gland on to the stem to hold it in position. This plan is a poor one, as the valve may shift, and then a

bad cylinder head is the result. Always block a piston or cross-head at the back end of the guides, for if the blocking should get loose, the front head, which is the cheaper, would alone suffer. A better plan than carrying blocking for the cross-head is to have the blacksmith make a hook out of 1½-inch round iron, also a flat piece or bar 15 inches long, 1½ or 2 inches thick, and 4 inches wide, with a hole through its center for the shank of the hook to pass through—the shank being threaded for a nut. When it is necessary to block a piston, get it to the back end of the guides, pass the hook round the cross-head wrist and the shank through a hole in the other piece which rests against the face of the yoke supporting the back end of the guides, run up a nut on the shank of the hook hard against the bar, and the piston is secured. Two nuts are better than one, the outside one being jammed on to the other.

If a leading wrist-pin breaks, the main and side rods on that side and the side rod on the other side must come down, the piston must be blocked, and the valve stem disconnected. In case of the breaking of a back pin, both side-rods must come down.

If a valve stem breaks, take it down, also the main rod on that side, in the meantime blocking the piston. If the stem is broken outside of the chest, let the piece remain in the stuffing-box, fill in some packing, and screw up the gland.

If the back-up eccentric rod breaks, take both eccentric rods down on that side of the engine. If it is a

go-ahead rod, it alone may come down with the straps, also the main rod and valve stem on that side. The main rod and valve stem should also be disconnected in the case of a broken back-up eccentric rod, and in either case the link should be disconnected from the tumbling-shaft by disconnecting the hanger.

If the lifter tumbling-shaft, arms, saddle-pin, or reach-rod breaks, a piece of wood may be fitted and tied in between the block and top of the link slot for the link to rest on. The piece should be long enough to raise the link to cut-off where the engine is desired to run.

In case of a broken reach-rod or tumbling-shaft, both links must be blocked up as described. As the engine will then have to be held entirely with the brake, great care will be necessary.

For broken eccentric straps or eccentrics, proceed as in case of eccentric rods. For a slipped eccentric—assuming it to be the go-ahead one, and the engine a link engine—put the engine on the center on the side of the slipped eccentric, pull the reverse lever into the full back-up notch, mark the valve stem flush with the gland with a knife blade, throw the lever in the full go-ahead notch, turn the slipped eccentric till the mark on the stem reappears in the same position as when marked, notice that the slipped eccentric is not in the same position as the back-up eccentric, but the full part or belly nearly opposite, and then go ahead.

In the case of [illegible] the bro' spring [illegible]

chain is carried, in which case the end of the spring may be held by the new hanger or the chain, it being necessary to jack up the back part of the engine, under the foot-board, to take the weight off and allow the insertion of the hanger or chain. If neither hanger nor chain can be had, slip a block of wood or rubber under the end of the equalizer, thick enough to raise it about level, the weight being removed from it by jacks under the foot-board. If the engine has far to go, or has a train to pull, it will be best to put a block of wood over the driving-box, between it and the frame, and over the wheel where the hanger is broken, to ease the other spring. If jacks are not carried, the driver may be run on to a stick of wood 4 or 6 inches in thickness, placed under the forward wheel to take the weight from the back wheel, and *vice versa*.

A broken spring should be treated the same as a broken spring hanger.

A broken equalizer should be removed, as it may get into the wheels, also the springs and wooden pieces placed over the driving boxes to keep the frame up.

A broken tire, if clear off, requires the wheel center to be kept from the rail, either by running the wheel on to a block of wood, or by jacking up under the wrist-pin and fitting a piece of wood between the oil bar and pedestal brace. The two side-rods should one down if the tire is a back or forward one, and so the main rod on that side. If the engine has far pull, it is better to remove the oil in its place to

give a proper bearing for the shaft, as otherwise the shaft will rest on the thin edges of the oil box—a bearing entirely insufficient, if any distance is to be run, or a load pulled. The writer has seen engines brought in with broken tires and the shaft running on the oil cellars, the bearings being so badly cut as to make it necessary to remove the wheels, re-turn the bearings, and fit new driving-box gibs or brasses.

It should be remembered that whenever the main rod is disconnected, the piston must be blocked and the valve stem disconnected.

A broken front truck wheel or axle can usually be chained up with the help of jacks under the front end, so as to get on a side track. The engine should be run very slow.

An unshipped throttle requires that the steam pressure be reduced, pulling the valve stem into the middle notch to shut off, and when taking water, the driving wheels to be blocked with sticks of wood when the tender is in the right position.

A burst flue can be plugged with a wooden plug, or, better still, with an iron one held in a pair of tongs or some special device for that purpose.

If a driving axle breaks so as to leave the wheels in position, the engine may generally be run alone on to a side track, and extra wheels and axles sent for.

A broken cylinder head requires that the main rod on that side should come down, and the ports covered by the valve and the valve stem disconnected.

If the steam chest or branch pipe in front end breaks,

CHAPTER XXII.

HOW MUCH WILL A LOCOMOTIVE PULL?

IT may be stated, generally, that the means by which a locomotive exerts its power in drawing trains is simply the friction or adhesion of the driving wheels on the rails; or to quote from Pambour's old "Treatise on Locomotive Engines:" "Two conditions are necessary in order that an engine may draw a given load. First that the dimensions and proportions of the engine and its boiler enable it to produce on its pistons, by means of the steam, the necessary pressure, which constitutes what is properly termed the power of the engine; and, second, that the weight of the engine be such as to give a sufficient adhesion to the wheels on the rails. These two conditions of power and weight must be in concordance with each other, for if there be a great power of steam and little adhesion, the latter will limit the effect of the engine, and there will be steam lost; if on the other hand, there be too much weight for the steam, that weight will be a useless burden, the limit of the load in that case being marked by the steam."

In the early days of locomotives it was thought that the adhesion or friction of the driving wheels on the rails would not be sufficient to enable such machines

"At speeds under 20 miles per hour it appears from the table that, when the rails are dry, the co-efficient of friction, or the adhesion, is one-fifth of the weight, and that on very dry rails it is one-fourth. As the speed is increased, the adhesion is reduced. These data are corroborative of the results of the author's experiments on the ultimate tractive force of locomotives on dry rails, from which he obtained a co-efficient of friction equal to one-fifth of the weight, at speeds of about 10 miles per hour."

It will thus be seen that the co-efficient of adhesion, as given by these authorities, varies all the way from one-twentieth to over one-third. It is no wonder then that a young engineer in taking up this subject should be a little perplexed to know what data to take in making his calculations. Even if he leaves out the maximum and minimum and takes what these authorities regard as "an average ordinary value," he will be still very much perplexed. Thus Wood gives $\frac{1}{15}$, Rankine, $\frac{1}{10}$, Molesworth and Clark $\frac{1}{5}$. In fact, the differences are so great that we are led to believe that some or all of these writers must have been quite mistaken in their facts or their theories on the subject. Recent experiments have made it plain that such was the case.

In reading what these writers have written on this subject, it is nowhere apparent that they made any distinction between sliding and rolling friction, or static and dynamic adhesion. Now every locomotive runner knows that after an engine begins to slip its wheels it will not exert as much power as it will before they be-

"On dry rails it was found that the co-efficient of adhesion of the wheels was generally over 0·20. In some cases it rose to 0·25 or even higher. On wet or greasy rails, without sand, it fell as low as 0·15 in an experiment, but averaged about 0·18. With the use of sand on wet rails it was above 0·20 at all times; and when the sand was applied at the moment of starting, so that the wind of the rotating wheels did not blow it away, it rose up to 0·35 and even above 0·40."

This is probably the most correct determination of the adhesion of wheels that has ever been made, and shows that the ordinary rule of taking the adhesion at one-fifth of the weight in the driving wheels is quite within the limits of ordinary practice. Even on a wet or greasy rail, with the use of sand, it was above 0·20 at all times. In fact, if we want to calculate the maximum power which a locomotive will exert if the rails are sanded, we might take the adhesion at one-third, and would be quite safe at one-fourth.

In order to put these figures in a form in which they can easily be remembered and conveniently used, they may be given as follows:

ADHESION OF LOCOMOTIVES.

Under ordinary conditions, without using sand on the rails, or on wet, sanded rails	One-fifth the weight on the driving-wheels.
Under favorable conditions, without sand	One-fourth the weight on the driving-wheels.
On a dry, sanded rail . . .	One-third the weight on the driving-wheels.

the quotient to the resistance due to the speed on a straight and level track.

Our knowledge of the resistance due to curves, like that due to speed, is in a very unsatisfactory condition, but the most reliable information we have indicates that the resistance is equal to about half a pound per ton per degree of curvature.

We may then tabulate these calculations as follows:

RESISTANCE OF TRAINS.

On straight and level track at very low speeds . . .	6 lb.	per ton of	2,000 lb.
For resistance due to speed: Square the velocity in miles per hour and divide by 172	. . lb.	"	"
For resistance due to grade: Multiply the rise in feet per mile by 0·3815 . . .	. . lb.	"	"
For resistance due to curves: Add ½ lb. per degree of curvature	. . lb.	"	"
Total	. . lb.	"	"

If the radius of the curve is given, the "degree" may be found approximately by dividing the radius into 5,730. This rule is correct enough for ordinary curves of over 500 feet radius.

Having these data, suppose we want to calculate how much, say, a Consolidation engine will pull up a grade of 70 feet per mile, with 9° curves and at a speed of 20 miles per hour. The first question to determine will be whether we want to know the maximum load

which such an engine will draw, or what it will do in good weather, or what it will do at all times. In the first case we would take the adhesion at $\frac{1}{3}$ the weight on the driving wheels; in the second at $\frac{1}{4}$, and in the last case at $\frac{1}{5}$. We will assume that the second represents our hypothetical case, and that the locomotive has a weight of 11,000 lb. on each driving wheel, or a total of 88,000 lb. The adhesion would therefore be one-fourth of 88,000 lb. = 22,000 lb. The train resistance per ton would be as follows:

Resistance on straight and level track =		6·0 lb.
" due to speed = $\frac{20 \times 20}{172}$ =		2·3 "
" " " grade = 70 × 0·3815 =		26.7 "
" " " curve = 9 × ½ =		4·5 "
Total		39·5 "

Therefore, as each ton will have a resistance of 39·5 lb., and as our engine is capable of exerting a tractive force of 22,000 lb., the total load which it can pull would be represented by

$$\frac{22{,}000}{39{\cdot}5} = 556{\cdot}8 \text{ tons.}$$

As the engine and tender weigh about 72 tons, the train which our engine will pull will be represented by 556·8—72 =484·8 tons, which is equal to about 24 loaded cars. Of course, to do this work the cylinders must be large enough to turn the wheels, and the boiler have the requisite capacity to supply steam.

For the calculation of the size of the cylinders, there [illegible] here to give a simple rule, which is only

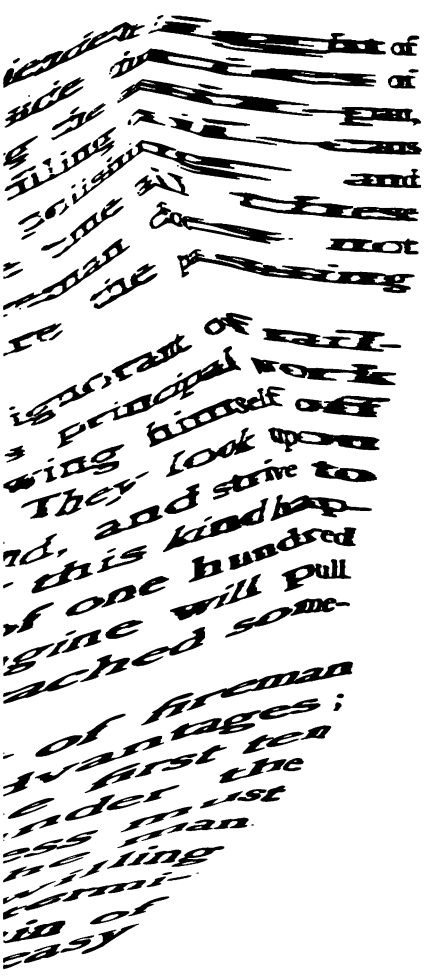
approximately correct, but near enough for ordinary purposes. This is: Multiply the total weight on the driving wheels in tons (of 2,000 lb.) by their diameter in inches; then four times the product will be the cubical capacity of one cylinder, or rather of the space swept through by the piston during a half revolution of the wheels. Having the cubical contents of the cylinder, the diameter can readily be found from the stroke, or the stroke from the diameter.—*Railroad Gazette.*

been evolved from experience with the kind
ıt adapted to fill the position. In the early
ɛ railroad world, when such men as George
ı, Horatio Allen, John B. Jervis, Ross Win-
ɔther pioneer engineers, demonstrated the
operation of the locomotive, they usually
r the care of their engines to the men who
d in constructing the machines, or in putting
her. This was the best that could be done
e, and the men selected generally proved
for the trust reposed in them; but it gave
ɛlief that no man could run a locomotive
y unless he was a machinist. The pos-
mechanical skill necessary for making
s considered the best recommendation for
ɛr. Under this system, all that a machinist
ed to do—so that he could graduate as a
! engineer—was to practice moving engines
ıe yard for a few days, when he was reported
ıe road. Akin with this sentiment was that
ɔmmended youths, of natural mechanical
he position of locomotive engineer, without
them to any previous special training.
rom mechanical institutes were deemed
running an engine as soon as they were
tain about how to start and stop the ma-
late Alexander L. Holley used to relate
of this kind of an engineer. During a
storm, the train Holley was traveling on
alled in a snow-bank. In her struggles

ıps the first-class engineer, is amassed by general
r during years of vigilant observation on the foot-
d, amidst many changes of fair and foul weather.
s passing through the occupation of fireman was
only way men could obtain practical knowledge
ngine running before taking charge, railroad offi-
all over the world gradually fell into the way of
rding that as the proper channel for men to trav-
before reaching the right-hand side of the loco-
ive.

s the pay for firemen rules moderately good, even
n compared with other skilled labor, and, as the
er position of engineer looms like a beacon not far
d, there is always a liberal choice of good men to
n work as firemen. Most railroad companies
gnize the importance of exercising judgment and
etion in selecting the men who are to run as their
e engineers. Sobriety, industry and intelligence
essential attributes in a fireman who is going to
e a success in his calling. Lack in any one of
e qualities will quickly prove fatal to a fireman's
pects of advancement. Sobriety is of the first im-
ance, because a man who is not strictly temperate
ld not be tolerated for a moment about a locomo-
since he is a source of danger to himself and
s; industry is needed to lighten the burden of a
an's duties, for oftentimes they are arduous be-
the conception of strangers; and wanting in the
quality, intelligence, a man can never be a good
n in the wide sense of the word, since one de-

reatly in vogue in Europe, and on certain of the
r roads of America, and it has many features to
mmend it over the practice of placing men en-
y devoid of railroad experience upon engines. It
tter for the men themselves, since working about
nes familiarizes them to some extent with the
t they are expected to do as an engineer's helper,
hat is really a fireman's position; it is better for
ompany, since the officers get the opportunity of
rving a man's habits before his receiving training
entails some expense; it is better for the engineer,
his assistant is not entirely strange to the work
s expected to do. A youth entirely unacquainted
all the operations which a fireman is called upon
erform finds the first trip a terribly arduous ordeal,
with some previous experience of railroad work.
n his first trip introduces him to the locomotive
o railroad life at the same time, the day is certain
a record of personal tribulation. To ride for ten
elve hours on an engine for the first time, stand-
n one's feet, and subject to the shaking motion,
ensely tiresome if a man has no work to do. But
e he has to ride durin[illegible] period, and in addi-
has to shovel six [illegible]ns of coal, most of
h has to be handle[illegible] job proves no sine-
. Then the postu[illegible]y while doing work
w; he is expec[illegible]ired to pitch coal on
rtain exact sp[illegible] small door, while the
ne is swingi[illegible]t he can scarcely keep
eet; his ha[illegible]d with the shovel and



Practice combined with inte
ually makes a man familiar
firing, as adapted to all varie
gets to understand intimately a
be met with, good, bad and
perience widens, his fire-mana
accord with the kind of coal
properties of the engine, the
character of the road and of th
all the details connected with
of his work, the object of pre
good man does not allow thi
attending regularly and exactl
tine duties.

There is a familiar adage a
a good fireman is certain to
and it rarely fails to come o
firemen of three months' sta
might conclude that they kr
running than the oldest engine
are not the good firemen. G
own business with the humil
and they do not undertake to
beyond their own knowledge.
into the heart of a subject, wh
there is to learn, and is there
his own acquirements, that su

When a fireman has master
to keep them going smoothl
for watching the operations of

skill is not obtained
he gradual accumu-
ient labor.
foreman, a man of ex-
and repairing engines,
al trip. A side rod pin
h he was leaning out of
observe anything wrong
him in the eye. An
ing the rods would have
affairs before babbit was

inexperienced man to control
at night, when the conditions
s the slipping of the drivers.
tter enough to those who feel
e engine; but the novice has
slipping vibration developed,
on his eyesight or his hearing
k stormy night the eye is use-
dging as to the regularity of the
e howling wind or rain rattling on
e sound of the exhaust. Under
is kind, an engine might jerk her
empirical engineer discovered she

ice with the handling and ordinary
otive extends, the aspiring fire-
the packing of glands, and how
o as to run to the best advan-

best to be done under all contingencies that can be conceived, prepare a man to act promptly when a break-down occurs.

CHAPTER XXIV.

USEFUL NOTES.

STEEL AND STEEL MAKING.

THERE are two kinds of crucible steel, pot steel and cemented steel. The first, as its name indicates, is carbonized in the pot or crucible, and after being melted is cast into an ingot suited to the work in hand. It is thus made: A quantity of wrought-iron, steel scraps, powdered charcoal and flux are packed in a plumbago crucible, having a cover luted tight, and melted down, the quality of the iron and amount of charcoal and scrap determining the kind of steel made. Spring steel, for instance, being of a high grade of carbonization, requires more charcoal than tool-steel; while tool-steel, requiring great toughness, tenacity, and uniformity of quality, is made of a finer kind of iron, gene[illegible] Swedes or Norway—of a special mark or bran[illegible] is the system emp[illegible]d generally in Am[illegible] mills, and it h[illegible] ntirely [illegible] fa[illegible] as quality [illegible] pr[illegible] [illegible] for a [illegible] [illegible] [illegible]

position midway between crucible and pneumatic steels, and being a formidable rival to the first, it has many peculiarities of nature which are not fully understood, and which prevent it from supplanting crucible steel in any work where cutting edges are required, such as axes and carpenters' tools generally. It is capable of being hardened, but not tempered, and there is a vast difference in these two stages. If Siemens-Martin steel is chilled, and the resulting hardness drawn, as in crucible steel, when a chisel is made the temper runs right down; the color shown is quite unlike crucible steel, being much duller and altogether different in aspect; while the condition of the cutting edge lacks durability. It seems to be more like case-hardening than tempering.

HEATING STEEL.

Much of the difficulty experienced by machinists in occasional attempts to forge their own tools comes from improperly heating the steel. To produce a good cutting tool, steel should be heated no more than is necessary to forge and temper. Follow the advice so frequently given to heat slowly, but at the same time avoid being too long in heating. The best results are obtained by a moderate, even heat, until the proper degree is reached, and then forging at once. It is a great but common mistake to allow the piece to come to the proper heat and then lie in the fire with the blast shut off for some minutes.

While this should not be done in the process of forging, the practice should be particularly guarded

the water until perfectly cold. Rub the tool with sandstone or other article that will give it a bright surface, so you can see the color. Heat an iron, and hold the tool on the iron until the color comes to a straw shade, then cool it so it will run no lower. The hardness indicated by the above shade is suitable for almost all kinds of turning tools for wood or metal. For cold chisels, let the color run lower, or to a light blue.

WATER ANNEALING.

Heat the steel to a red heat, and let it lie a few minutes, until nearly black hot; then throw it into soapsuds; steel in this way may be annealed softer than by putting it into the ashes of the forge.

MILD STEEL IN THE WORK-SHOPS.

The occasional failure of steel plates in boiler and other work, says the *Engineer and Iron Trades Advertiser*, is generally attributed to want of sufficient information on the part of the workmen. To prevent, as far as practicable, the possibility of failure in steel plates, caused by deficient information as to the proper method of treating this material, the Steel Company of Scotland has published and directs the attention of the users of the steel to the following rules:

"1. Welding: In welding mild steel plates, it is not necessary to heat them to the same high temperature as in the case of iron. Instead of a 'welding heat,' a bright yellow heat is sufficient; and if flux is required, it need only be three parts clean sand to one part common salt, moistened, and thrown on the parts in

The expense of building steel boilers is but little more than that of first-class iron, while the additional security given is worth much larger outlays and efforts.

ANNEALING STEEL.

Annealing at a high heat is injurious. Annealing at a low heat can do no harm to steel which is to be hardened afterwards, and if applied to steel which has been heated too hot for either forging, annealing or hardening, will, to a great extent, restore such injured steel. *Heat low*, thereby keeping steel which is good all right, and making that which has been injured better.

HOW TO TEMPER A DRILL VERY HARD.

Heat your drill to a cherry-red and quench it in mercury. This will drill hardened steel.

GOOD TAPS AND DIES.

Nothing is more essential in a machine shop than good accurate taps and dies.

MAKING A TAP.

In making a tap, when it is necessary to file a clearance in the threads, it will be found of advantage to heat it until it becomes blue, before filing; the difference between that color and the newly-filed portions being an excellent guide in the filing. This will apply to reamers and many other tools.

TO TURN CHILLED IRON.

At Lister's Works, Darlington, England, some articles required turning in the lathe, and cast steel could

ne of the above incident, valued each engine
er day upon the road, while the actual cost of
d finished was less than $2.

)ther case some brass rivets were required for
a new boiler jacket. A requisition was made,
· a delay of one week the information came
·e were no such rivets in the market, when it
known that the necessary quantity of rivets
: bought for ten cents in any of the leading
e stores. Some brass wire was ordered, a set
were made, and after making the necessary
of rivets the jacket was put together. Much
on was afforded the master mechanic from the
t before the engine left the shop a large box
ıe rivets desired was received, being a sufficient
to last the company until their lease expires,
ill be about ninety years hence.

tain railroad company were persuaded to pur-
e patent right to use a particular style of cast-
king rings, which after a while proved to be
s. The master mechanic proposed to abandon
)f the rings, which proposition was met with a
derision by a superior officer, accompanied
statement that the company had paid a large
the right to use the packing, and they were
; to abandon it. The result is that the cylin-
he locomotives are badly worn and cut, in-
:ing quite common where the bottoms of the
are worn 3-16ths of an inch below where
ıt to be. When one of these engines was

ploy any apprentices—without a consultation with a superior. There are in the shop referred to certain apprentices who are relatives or friends of officials, and they neither work themselves nor allow the other boys to do so when they can prevent it. We have seen these young rascals stand up and defy the master mechanic to discharge them, as they would come back again. Such treatment is greatly humiliating and cutting, particularly to a sensitive man, and when these instances occur he wishes himself out of the country.

It is of the greatest importance to the company that the master mechanic be thoroughly instructed in his position, and the more he knows the better will he be enabled to discharge the duties of it, and the more carefully will the interests of the company be served.

To this end every reasonable means should be supplied for experiment, and opportunities afforded to visit other roads, in order to study the different methods of doing work. We remember a circumstance where the president of a railroad refused to allow the master mechanic to attend the conventions of the American Master Mechanics' Association, considering it a loss of time; besides, he thought it detrimental to the interests of his company to allow the master mechanics to get their heads so full of different ideas. It is, perhaps, unnecessary to add that improvements were seldom made upon the motive power of that road. Railroad officials should not expect to realize satisfactory results from every experiment, and admonish the experimenter for his seeming extravagance, but rather en-

established rule to remove the side rods from passenger engines after they have been in constant use three years, and replace them with new ones. The fact is that many railroad companies run their machinery until it breaks down, then scientifically reflect upon what they make out to be an unavoidable accident, when, in reality, it was the result of carelessness and neglect. We have a case in mind where an engineer reported several spokes broken in the main driving wheel of a passenger engine. The wheel was examined by the master mechanic, who declared it would run for some time yet. The engineer remonstrated, but all to no purpose, and one day the train was behind time, and a telegram announced that "No. 9" had broken a driving wheel and was helpless. The tire upon the broken wheel had burst, and all that was left of the wheel was the hub and two or three spokes. The tire had broken into five pieces, which, together with pieces of the wheels, had been hurled in all directions, completely divesting the right-hand side of the engine of rods, wheel covers, pipes, and a portion of the cab, and barely grazing the head of the engineer. This was reported to the directors as an unavoidable accident, when, in reality, it was expected by the engineer every day for several months before it happened. Cases are on record of cracked driving wheels running for years without giving way, but they are exceptional. Where there appears to be danger it should be remedied at once, and thus spare the company the humiliation of being sharply criticised by the pı and

besides being damaged far beyond the cost of necessary repairs, made in time.

Some master mechanics are continually altering the valves and nozzles of their engines, in order to make them steam better and work with greater economy, yet they neglect to insist upon taking proper care of the boilers. These are allowed to run for months, in some cases, without being washed out. Let a boiler become fouled by scale and mud, and enormous losses are sustained. For instance, the heat-conducting power of iron is about thirty times greater than compact scale, therefore, when the scale is allowed to attain any considerable thickness, a great deal of heat is lost.

This loss of heat, as will readily be seen, also reduces the capacity of a boiler.

As a rule, locomotive boilers have too many tubes located from $\frac{3}{8}''$ to $\frac{7}{16}''$ apart. Such boilers can use dirty or chemically impure water but a short time before the tubes become coated with scale, and the spaces intended for water become nearly, sometimes entirely, closed.

In one instance we observed the cleaning of a boiler that had been in use for five years, during which time the cylinder part had not been washed, because it was not accessible. The leg, however, had been washed about once every two months. When the tubes were removed, they were coated with scale about $\frac{3}{16}''$ to $\frac{1}{4}''$ thick, and there were two ash-cart loads of dirt taken from the tubes and cylinder part of the boiler. In view of the fact that the lower rows of tubes, say

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Brake.

A block or strap applied to the rim of a wheel, used to check its motion and bring it to a stop.

Cam.

A pulley turning on a shaft out of its centre. When made round and encircled by a strap, and used to work the valves of a steam engine, it is called an eccentric. It is a substitute for a small crank.

Check-valve.

See Valve.

Cab.

The house used to protect the engineer and fireman from the weather.

Counter-balance.

A large block of metal secured between two or more arms of the driving wheels, to balance the momentum of the moving machinery connected with the wheels.

Connecting Rod.

A rod to communicate the pressure on the piston to the crank-pin.

Crank.

In outside cylinder engines, the crank is formed by a pin in the wheel called the crank pin. The crank converts the rectilinear motion of the piston into the rotary motion of

Cut-off Valve.

An additional valve—not indispensable, and seldom used on locomotives—to shut off or cut off the admission of steam to the cylinder when the piston has only completed a part of its stroke.

Cylinder.

A cylindrical vessel closed at its ends by covers or heads. Steam is admitted at each end alternately, to press upon a block called the piston. The piston is made to fit steam-tight by means of packing rings to the inner circumference of the cylinder, and the action of the steam keeps it in motion from one end of the cylinder to the other.

Damper.

A door, used to exclude air from the furnace.

Dome.

An elevated chamber on top of the boiler, from which steam is taken to the cylinders.

Driving Wheels.

Those wheels turned directly by the moving machinery of the engine, and which, by their adhesion to the rails, propel the engine along.

Eccentrics.

See Cam.

Eduction Port.

ually call exha ist port." A passage on the to ad away the waste (exhaust) to e blast pipe.

Equalizing Lever.

A bar suspended by its centre beneath the frame, and connected at each end to the springs of the driving wheels; used to distribute any shock or jolt between both pairs of wheels.

Fire-Box.

The furnace of a boiler.

Foaming.

An artificial excitement, or too great ebullition of the water level, caused by too much water, greasy or dirty water, or malformation of the boiler. When foaming takes place the water in the glass gauge is violently agitated, and the gauge cocks show a frothy mixture—neither clear steam nor solid water.

Foot-Board.

A plate iron floor behind the boiler in the cab, upon which the engineer and fireman stand.

Frame.

Made to attach to the boiler, cylinders, axles, and all cross shafts. Used to bind the whole fabric together.

Glass Gauge.

A thick glass tube attached to the boiler, to show the height of the water in the boiler.

Gauge Cocks.

Small cocks inserted in the boiler at different levels to show the height of water, same as the glass gauge. When opened, water or steam will escape, according as the level of the water is above or below them.

Gland.

A bushing to secure the packing in a stuffing-box.

Grate.

The bars supporting the fuel in the furnace.

Guides.

Rods or bars lying in the direction of the axis of the cylinder. Used for guiding the cross-head to insure a perfectly parallel motion in the piston rod.

Induction Ports.

Generally called steam ports. Two passages on top of the cylinder to admit steam within it—one port to each end.

Journal.

The part of a shaft or axle resting in a box.

Lagging.

A wooden sheathing around a boiler or cylinder, to prevent the radiation of heat.

Lap.

The distance which the valve overlaps on each end over the induction or steam ports, when in the middle of its travel.

Lead.

The distance which the steam port is opened when the piston begins its stroke.

Link Motion.

An arrangement for working the valves, fully described in the body of this book.

Man-hole.

A hole to admit a man within the boiler for cleaning or repairs.

Mud-holes.

Usually called "hand-holes." Small openings at the bottom of the water space around the fire-box. Used to clean out the mud and other deposits from the water.

Packing.

Any substance used to make a joint steam or water tight.

Piston.

See Cylinder.

Piston Rod.

A rod secured at one end within the body of the piston, and at the other to the cross-head. This rod passes through the cylinder cover, and is made steam-tight by packing secured in a recess outside of the cover called a stuffing-box.

Plug.

A lead plug tapped in top sheet of furnace to melt and give warning when water falls below it.

Plunger.

The solid piston of a pump, pressing only by one end against the water.

Ports.

Passages or openings for the entrance and exit of steam to and from the cylinders.

Priming.

Usually called foaming. The passage of foam along with the steam into the cylinder engine is working.

APPENDIX.

TABLE OF TIME

Occupied in running One Mile, Speed in Feet per Minute, and Number of Revolutions of the Driving Wheels, or Double Strokes of the Piston, per Minute, at the following given speeds:

Speed per Hour.	Speed per Minute.	Time of running 1 mile.		Revolution of Wheels, per Minute—the Diameter of Wheels being in Feet.										
				3 feet.	3½ ft.	4 feet.	4½ feet.	5 feet.	5½ feet.	6 feet.	6½ feet.	7 ft.	7½ feet.	8 feet.
Miles.	Feet.	Min.	Sec.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
10	880	6	00	93.37	80	70.	62.25	56.02	50.93	46.68	43.09	40	37.35	35.01
11	968	5	27	102.71	88	77.	68.47	61.62	56.02	51.35	47.40	44	41.08	38.51
12	1056	5	00	112.04	96	84.	74.70	67.23	61.12	56.02	51.71	48	44.82	42.02
13	1144	4	37	121.37	104	91.	80.92	72.73	66.21	60.69	56.02	52	48.55	45.52
14	1232	4	17	130.70	112	98.	87.14	78.33	71.30	65.36	60.33	56	52.29	49.
15	1320	4	00	140.06	120	105.	93.37	84.03	76.40	70.03	64.64	60	56.02	52.53
16	1408	3	45	149.39	128	112.	99.69	89.63	81.50	77.70	68.95	64	59.76	56.
17	1496	3	32	158.72	136	119.	105.82	95.23	86.59	79.37	73.26	68	63.49	59.5
18	1584	3	20	169.06	144	126.	112.04	100.84	91.68	84.03	77.57	72	67.23	63.
19	1672	3	09½	178.39	152	133.	118.26	106.44	96.77	88.70	81.88	76	70.96	66.5
20	1760	3	00	187.72	160	140.	124.48	112.04	101.86	93.37	86.19	80	74.70	70.
21	1848	2	51½	197.05	168	147.	130.72	117.65	106.95	98.04	90.50	84	78.43	73.5
22	1936	2	43½	206.38	176	154.	136.94	123.25	112.04	102.71	94.81	88	82.17	77.
23	2024	2	36½	215 71	184	161.	143.17	128.85	117.14	107.38	99.12	92	85.50	80.5
24	2112	2	30	225.05	192	168.	149.40	134.45	122.24	112.95	103.43	96	89.63	84.
25	2200	2	24	233.48	200	175.	155.63	140.05	127.33	116.72	107.74	100	93.37	87.5
26	2288	2	18⅔	242.77	208	182.	161.85	145.65	132.42	121.39	112.05	104	97.14	91.
27	2376	2	13⅓	255.74	216	189.	168.07	151.26	137.52	126.05	116.36	108	100.87	94.5
28	2464	2	08½	261.43	224	196.	174.3	156.86	142.63	130.72	120.67	112	104.57	98.
29	2552	2	04	270.78	232	203.	180.52	162.47	147.74	135.38	124.98	116	108.32	101.5
30	2640	2	00	280.11	240	210.	186.74	168.08	152.85	140.04	129.30	120	112.02	105.
31	2728	1	56	289.52	248	217.	192.97	173,78	157.98	144.71	133.61	124	115.75	108.5
32	2816	1	52½	298.79	256	224.	199.20	179.39	163.	149.38	137.62	128	119.5	112.
33	2904	1	49	308.12	264	231.	205.42	185.	168.1	154.05	141.93	132	123.23	115.5
34	2992	1	45⅜	317.46	272	238.	211.64	190.60	172.99	158.72	146.24	136	127 06	119.
35	3080	1	42⅜	326.80	280	245.	217.13	196.21	177.29	163.33	150.85	140	130.69	122.5
36	3168	1	40	336.13	288	252.	224.09	201.82	182.4	168.	155.16	144	134.42	126.
37	3256	1	37¼	345.47	296	259.	230.32	207.42	187.5	172.67	159.41	148	138.16	129.5
38	3344	1	34¾	354.81	304	266.	236.54	213.03	192.6	177.34	163.72	152	143.90	133.
39	3432	1	32½	364.15	312	273.	242.77	218.63	197.95	182.05	168.03	156	145.63	136.5
40	3520	1	30	373 57	320	280,	252.72	224.24	203.76	186.72	172.40	160	149.36	140.
42	3696	1	25¾	392.15	336	294.	261.44	235.44	214.	196.05	181.02	168	156.83	147.
45	3960	1	20	420.17	360	315.	284.30	252.27	229.23	210.06	193.95	180	168.03	157.5
48	4224	1	15	438.18	384	336.	298.79	269.10	244.55	224.06	206.88	192	179.23	168.
50	4400	1	12	446.85	400	350.	315.90	280.30	254.75	233.70	215.50	200	186.70	185.
55	4840	1	05½	513.54	440	385.	347.49	308.33	280.17	256.74	237.05	220	205.37	192.5
60	5280	1	00	560.23	480	420.	379.08	336.36	305.64	280.5	258.6	240	224.04	210.1
65	5720	0	55⅓	606.91	520	455.	416.67	364.39	331.11	303.42	280.15	260	242.71	227.5
70	6160	0	51⅜	653.59	560	490.	442.19	392.42	356.58	326.76	301.70	280	261.38	245.
75	6600	0	48	700.28	600	525.	473.85	420.50	372.05	350.1	323.25	300	280.05	262.5
80	7040	0	45	746.96	640	560.	505.50	448.48	407.60	373.44	344.80	320	298.72	280.
85	7480	0	42½	792.74	680	595.2	528.38	476.50	433.25	396.77	346.35	340	317.42	297.6
90	7920	0	40	840.34	720	630.27	560.23	504.62	458.65	420.11	367.90	360	336.	315.14

Algebraic Signs as applied in Mechanical Calculations.

=Sign of equality, and signifies equal to, as 2 added to 5=7.
+Sign of addition, and signifies plus or more, as 4+2=6.
−Sign of subtraction, and signifies minus or less, as 7−5 =2.
×Sign of multiplication, and signifies multiplied by, as 7×6 =42.
÷Sign of division, and signifies divided by, as 20÷5=4.
√Sign of square root, ∛Sign of cube root } evolution, or the extraction of roots, thus √81=9 ∛729 =9.

Fractions of a foot in Inches.	Decimal Value in Feet.	Area in Feet.	Circumference in feet.	Fractions of an Inch.	Decimal Value.	Fractions of an Inch.	Decimal Value.
11	.9166	.6598	2.879	1/2 & 1/32	.96875	31/32 & 1/32	.96875
10	.8333	.54537	2.617	1/2 & 1/16	.9375	31/32 & 1/16	.9375
9	.75	.44178	2.356	1/2 & 1/32	.90625	31/32 & 1/32	.90625
8	.6666	.33779	2.094	3/4 & 1/32	.875	1/2 & 1/32	.875
7	.5833	.26722	1.832	1/2 & 1/32	.84375	31/32 & 1/32	.84375
6	.5	.19635	1.57	1/2 & 1/16	.8125	1/2 & 1/16	.8125
5	.4166	.1363	1.308	1/2 & 1/32	.78125	1/2 & 1/32	.78125
4	.3333	.08724	1.047	3/4	.75	1/4	.75
3	.25	.04908	.7854	1/2 & 1/32	.71875	1/4 & 1/32	.21875
2	.1666	.02179	.5233	1/2 & 1/16	.6875	1/4 & 1/16	.1875
1	.0833	.00544	.2616	1/2 & 1/32	.65625	1/4 & 1/32	.15625
1/2	.07291	.00417	.22907	1/2	.625	1/8	.125
1/4	.0625	.00306	.19635	1/2 & 1/32	.59375	3/32	.09375
1/8	.05208	.0028	.16362	1/2 & 1/16	.5625	1/16	.0625
1/16	.04166	.00136	.130899	1/2 & 1/32	.53125	1/32	.03125
1/32	.03125	.00076	.098174	1/2	.5		
1/64	.02083	.000.35	.06545				
1/128	.01041	.000085	.032719				

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
9/16	16.3492	14.3335	7 in.	38.4846	21.9912
5/8	16.8001	14.5299	1/16	39.1749	22.1875
1 1/16	17.2573	14.7262	1/8	39.8713	22.3839
3/4	17.7205	14.9226	3/16	40.5469	22.5802
1 3/16	18.1900	15.1189	1/4	41.2825	22.7766
7/8	18.6655	15.3153	5/16	41.9974	22.9729
1 5/16	19.1472	15.5716	3/8	42.7184	23.1693
			7/16	43.4455	23.3656
5 in.	19.6350	15.7080	1/2	44.1787	23.5620
1/16	20.1290	15.9043	9/16	44.9181	23.7583
1/8	20.6290	16.1007	5/8	45.6636	23.9547
3/16	21.1252	16.2970	1 1/16	46.4153	24.1510
1/4	21.6475	16.4934	3/4	47.1730	24.3474
5/16	22.1661	16.6897	1 3/16	47.9370	24.5437
3/8	22.6907	16.8861	7/8	48.7070	24.7401
7/16	23.2215	17.0824	1 5/16	49.4833	24.9364
1/2	23.7583	17.2788			
9/16	24.3014	17.4751	8 in.	50.2656	25.1328
5/8	24.8505	17.6715	1/16	51.0541	25.3291
1 1/16	25.4058	17.8678	1/8	51.8486	25.5255
3/4	25.9672	18.0642	3/16	52.8994	25.7218
1 3/16	26.5348	18.2605	1/4	53.4562	25.9182
7/8	27.1085	18.4569	5/16	54.2748	26.1145
1 5/16	27.6884	18.6532	3/8	55.0885	26.3109
			7/16	55.9138	26.5072
6 in.	28.2744	18.8496	1/2	56.7451	26.7036
1/16	28.8665	19.0459	9/16	57.5887	26.8999
1/8	29.4647	19.2423	5/8	58.4264	27.0963
3/16	30.0798	19.4386	1 1/16	59.7762	27.2926
1/4	30.6796	19.6350	3/4	60.1321	27.4890
5/16	31.2964	19.8313	1 3/16	60.9943	27.6853
3/8	31.9192	20.0277	7/8	61.8625	27.8817
7/16	32.5481	20.2240	1 5/16	62.7369	28.0780
1/2	33.1831	20.4204			
9/16	33.8244	20.6167	9 in.	63.6174	28.2744
5/8	34.4717	20.8131	1/16	64.5041	28.4707
	35.1252	21.0094	1/8	65.3968	28.6671
	35.7847	21.2058	3/16	66.2957	28.8634
	36.4505	21.4021	1/4	67.2007	29.0598
	37.1224	21.5985	5/16	68.1120	29.2561
	37.8005	21.7948	3/8	69.0293	29.4525
			7/16	69.9528	29.6488

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	70.8823	29.8452	12 in.	113.0976	37.6992
1/16	71.8181	30.0415	1/16	114.2788	37.8955
1/8	72.7599	30.2379	1/8	115.4660	38.0919
1/16	73.7079	30.4342	1/16	116.6645	38.2882
3/4	74.6620	30.6306	1/4	117.8590	38.4846
1/16	75.6223	30.8269	1/16	119.0648	38.6809
7/8	76.5887	31.0233	3/8	120.2766	38.8773
1/16	77.5613	31.2196	1/16	121.4946	39.0736
			1/2	122.7187	39.2700
10 in.	78.5400	31.4160	1/16	123.9490	39.4663
1/16	79.5248	31.6123	5/8	125.1854	39.6627
1/8	80.5157	31.8087	1/16	126.4479	39.8590
1/16	81.5128	32.0050	3/4	127.6765	40.0554
1/4	82.5160	32.2014	1/16	128.8999	40.2517
1/16	83.5254	32.3977	7/8	130.1923	40.4481
3/8	84.5409	32.5941	1/16	131.4279	40.6444
1/16	85.5626	32.7904			
1/2	86.5903	32.9868	13 in.	132.7326	40.8408
1/16	87.6243	33.1831	1/16	134.0120	41.0371
5/8	88.6643	33.3795	1/8	135.2974	41.2338
1/16	89.7105	33.5758	1/16	136.5890	41.4298
3/4	90.7627	33.7722	1/4	137.8867	41.6262
1/16	91.8212	33.9685	1/16	139.1907	41.8225
7/8	92.8858	34.1649	3/8	140.5007	42.0189
1/16	93.9566	34.3612	1/16	141.8169	42.2152
			1/2	143.1391	42.4116
11 in.	95.0334	34.5596	1/16	144.4726	42.6079
1/16	96.1164	34.7539	5/8	145.8021	42.8043
1/8	97.2053	34.9503	1/16	147.1428	43.0006
1/16	98.3008	35.1466	3/4	148.4896	43.1970
1/4	99.4021	35.3430	1/16	149.8426	43.3933
1/16	100.5097	35.5393	7/8	151.2017	43.5897
3/8	101.6234	35.7357	1/16	152.5670	43.7860
1/16	102.7432	35.9320			
1/2	103.8691	36.1284	14 in.	153.9384	43.9824
1/16	105.0012	36.3247	1/16	155.3159	44.1787
5/8	106.1394	36.5211	1/8	156.6995	44.3751
1/16	107.2838	36.7174	1/16	158.0893	44.5714
3/4	108.4342	36.9138	1/4	159.4852	44.7676
1/16	109.5909	37.1101	1/16	160.8374	44.9641
7/8	110.7536	37.3065	3/8	162.2956	45.1605
1/16	111.9226	37.5028	1/16	163.7099	45.3568

Diameters, Areas, etc.—Continued.

Dia.	Area.	Circum.	Dia.	Area.	Circum.
	165.1203	45.5522	17 in.	226.9806	53.4072
	166.5583	45.7495		228.6527	53.6035
	167.9996	45.9459		230.3308	53.7999
	169.4395	46.1422		232.0151	53.9962
	170.8795	46.3386		233.7065	54.1926
	172.3247	46.5349		235.4022	54.3889
	173.7729	46.7313		237.1049	54.5853
	175.2265	46.9276		238.8138	54.7816
				240.5287	54.9780
15 in.	176.7150	47.1240		242.2499	55.1743
	178.1907	47.3203		243.9771	55.3707
	179.6725	47.5167		245.7105	55.5670
	181.1105	47.7130		247.4500	55.7634
	182.6545	47.9094		249.1962	55.9597
	184.1548	48.1057		250.9475	56.1561
	185.6612	48.3021		252.7060	56.3524
	187.1737	48.4984			
	188.6923	48.6948	18 in.	254.4696	56.5488
	190.2171	48.8911		256.2398	56.7451
	191.7480	49.0875		258.0161	56.9415
	193.3351	49.2838		259.7986	57.1378
	194.8282	49.4802		261.5872	57.3342
	196.3776	49.6765		263.3820	57.5305
	197.9330	49.8729		265.1829	57.7269
	199.4947	50.0692		266.9900	57.9232
				268.8031	58.1196
16 in.	201.0624	50.2656		270.6225	58.2159
	202.6363	50.4619		272.4479	58.5123
	204.2162	50.6583		274.2895	58.7806
	205.8024	50.8546		276.1171	58.9056
	207.3946	51.0510		277.9610	59.1013
	208.9931	51.2473		279.8110	59.2977
	210.5976	51.4437		281.1672	59.4940
	212.2083	51.6400			
	213.8251	51.8364	19 in.	283.5294	59.6904
	215.4481	52.0327		285.3978	59.8867
	217.0772	52.2291		287.2723	60.0831
	218.7124	52.4254		289.4030	60.2794
	220.3537	52.6218		291.0397	60.4758
	222.0013	52.8181		292.9324	60.6721
		53.0145		294.8312	60.8685
		53.2108		296.7367	61.0648

DIAMETERS, AREAS, ETC.— *Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	298.6483	61.2612	22 in.	380.1336	69.1152
9/16	300.5658	61.4575	1/16	382.2965	69.3115
5/8	302.4894	61.6539	1/8	384.4655	69.5079
11/16	304.4192	61.8502	3/16	386.6907	69.7042
3/4	306.3550	62.0466	1/4	388.8220	69.9006
13/16	308.2971	62.2429	5/16	391.0095	70.0969
7/8	310.2452	62.4393	3/8	393.2031	70.2933
15/16	312.1996	62.6356	7/16	395.4029	70.4806
			1/2	397.6087	70.6860
20 in.	314.1600	62.8320	9/16	399.8207	70.8823
1/16	316.1266	63.0283	5/8	402.0388	71.0787
1/8	318.0992	63.2247	11/16	404.2631	71.2750
3/16	320.0781	63.4210	3/4	406.4935	71.4714
1/4	322.0630	63.6174	13/16	408.7301	71.6677
5/16	324.0542	63.8137	7/8	410.9728	71.8641
3/8	326.0514	64.0101	15/16	413.2317	72.0604
7/16	328.0548	64.2064			
1/2	330.0643	64.4028	23 in.	415.4766	72.2568
9/16	332.0800	64.5991	1/16	417.7377	72.4531
5/8	334.1018	64.7955	1/8	420.0049	72.6495
11/16	336.1297	64.9918	3/16	422.2783	72.8458
3/4	338.1637	65.1882	1/4	424.5577	73.0422
13/16	340.2040	65.3845	5/16	426.3434	73.2385
7/8	342.2502	65.5809	3/8	429.1352	73.4349
15/16	344.3028	65.7772	7/16	431.4331	73.6312
			1/2	433.7371	73.8276
21 in.	346.3614	65.7936	9/16	436.0473	74.0239
1/16	348.4267	66.1699	5/8	438.3636	74.2203
1/8	350.4970	66.3663	11/16	440.6811	74.4166
3/16	352.5740	66.5626	3/4	443.0146	74.6130
1/4	354.6571	66.7590	13/16	445.3539	74.8093
5/16	356.7465	66.9553	7/8	447.6992	75.0057
3/8	358.8419	67.1517	15/16	450.0418	75.2020
7/16	360.9435	67.3480			
1/2	363.0511	67.5444	24 in.	452.3904	75.3984
9/16	365.1650	67.7407	1/16	454.7497	75.5947
5/8	367.2849	67.9371	1/8	457.1150	75.7911
11/16	369.4110	68.1334	3/16	459.4866	75.9874
3/4	371.5432	68.3298	1/4	461.8642	76.1838
13/16	373.6816	68.5261	5/16	464.2481	76.3801
7/8	375.8261	68.7225	3/8	466.6380	76.5765
15/16	377.9768	68.9188	7/16	469.0341	76.7728

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	471.4363	76.9692	27 in.	572.5566	84.8232
9/16	473.8447	77.1655	1/16	575.2104	85.0195
5/8	476.2592	77.3619	1/8	577.8703	85.2159
11/16	478.6798	77.5582	3/16	580.5364	85.4122
3/4	481.1065	77.7546	1/4	583.2085	85.6086
13/16	483.5395	77.9509	5/16	585.8869	85.8049
7/8	485.9785	78.1473	3/8	588.5714	86.0013
15/16	488.4237	78.3436	7/16	591.2620	86.1976
			1/2	593.9587	86.3940
25 in.	490.8750	78.5400	9/16	596.6616	86.5903
1/16	493.3325	78.7363	5/8	599.3706	86.7867
1/8	495.7960	78.9327	11/16	602.0858	86.9830
3/16	498.2657	79.1290	3/4	604.8070	87.1794
1/4	500.7415	79.3254	13/16	607.5345	87.3757
5/16	503.2236	79.5217	7/8	610.2680	87.5721
3/8	505.7117	79.7181	15/16	613.0078	87.7684
7/16	508.2060	79.9144			
1/2	510.7063	80.1108	28 in.	615.7536	87.9648
9/16	513.2129	80.3071	1/16	618.5051	88.1611
5/8	515.7255	80.5035	1/8	621.2636	88.3575
11/16	518.2443	80.6998	3/16	624.0279	88.5538
3/4	520.7692	80.8962	1/4	626.7982	88.7502
13/16	523.3003	81.0925	5/16	629.5748	88.9465
7/8	525.8375	81.2889	3/8	632.3574	89.1429
15/16	528.3809	81.4852	7/16	635.1462	89.3392
			1/2	637.9411	89.5356
26 in.	530.9304	81.6816	9/16	640.7422	89.7319
1/16	533.4860	81.8779	5/8	643.5494	89.9283
1/8	536.0477	82.0743	11/16	646.3627	90.1246
3/16	538.6156	82.2706	3/4	649.1821	90.3210
1/4	541.1896	82.4670	13/16	652.0078	90.5173
5/16	543.7698	82.6633	7/8	654.8395	90.7137
3/8	546.3561	82.8597	15/16	657.6774	90.9100
7/16	548.9486	83.0560			
1/2	551.5471	83.2524	29 in.	660.5214	91.1064
9/16	554.1519	83.4487	1/16	663.3716	91.3027
5/8	556.7627	83.6451	1/8	666.2278	91.4991
11/16	559.3797	83.8414	3/16	669.0902	91.6954
3/4	562.0027	84.0378	1/4	671.9587	91.8918
13/16	564.6320	84.2341	5/16	674.8335	92.0081
7/8	567.2674	84.4305	3/8	677.7143	92.2845
15/16	569.4090	84.6268	7/16	680.6013	92.4808

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	683.4943	92.6772	32 in.	804.2496	100.5312
1/16	686.3936	92.8735	1/16	807.3943	100.7275
1/8	689.2989	93.0699	1/8	810.5450	100.9240
1 1/16	692.2104	93.2662	1 1/16	813.7020	101.1202
3/4	695.1280	93.4626	1/4	816.8650	101.3166
1 3/16	698.0518	93.6589	1/16	820.0343	101.5130
7/8	700.9817	93.8553	3/8	823.2096	101.7093
1 5/16	703.9178	94.0516	1/16	826.3911	101.9056
			1/2	829.5787	102.1020
30 ir	706.8600	94.2480	1/16	832.7725	102.2983
1/16	709.8083	94.4443	1/8	835.9724	102.4947
1/8	712.7627	94.6407	1 1/16	839.1784	102.6910
1/16	715.7233	94.8370	3/4	842.3905	102.8874
1/4	718.6900	95.0334	1 3/16	845.6089	103.0837
1/16	721.6629	95.2297	7/8	848.8333	103.2801
3/8	724.6419	95.4261	1 5/16	852.0639	103.4764
1/16	727.6271	95.6224			
1/2	730.6183	95.8188	33 in.	855.3006	103.6728
1/16	733.6158	96.0151	1/16	858.5436	103.8691
1/8	736.6193	96.2115	1/8	861.7924	104.0655
1/16	739.6290	96.4078	1/16	865.0475	104.2618
3/4	742.6447	96.6042	1/4	868.3087	104.4582
1 3/16	745.6667	96.8005	1/16	871.5760	104.6545
7/8	748.6948	96.9969	3/8	874.8497	104.8509
1 5/16	751.7291	97.1932	1/16	878.1290	105.0472
			1/2	881.4151	105.2436
31 in.	754.7694	97.3896	1/16	884.7070	105.4399
1/16	757.8159	97.5859	1/8	888.0051	105.6363
1/8	760.8685	97.7823	1 1/16	891.3090	105.8326
1/16	763.9273	97.9786	3/4	894.6196	106.0290
1/4	766.9921	98.1750	1 3/16	897.9369	106.2253
1/16	770.0632	98.3713	7/8	901.2587	106.4217
3/8	773.1404	98.5677	1 5/16	904.5875	106.6180
1/16	776.2237	98.7648			
1/2	779.3131	98.9684	34 in.	907.9224	106.8144
1/16	782.4087	99.1567	1/16	911.2645	107.0107
1/8	785.5104	99.3531	1/8	914.6105	107.2071
1 1/16	788.6183	99.5494	1/16	917.9640	107.4034
3/4	791.7322	99.7458	1/4	921.3232	107.5998
1 3/16	794.8524	99.9421	1/16	924.6883	107.7961
7/8	797.9786	100.1385	3/8	928.0605	107.9925
1 5/16	801.1111	100.3348	1/16	931.4380	108.1888

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
	934.8223	108.3852	37 in.	1075.2126	116.2392
9/16	938.2121	108.5815	1/16	1078.8482	116.4355
1/8	941.6087	108.7779	1/8	1082.4898	116.6319
1/16	945.0110	108.9742	3/16	1086.1376	116.8282
1/4	948.4195	109.1706	1/4	1089.7915	117.0246
1/16	951.8341	109.3669	5/16	1093.4517	117.2209
1/8	955.2550	109.5633	3/8	1097.1179	117.4173
1/16	958.6820	109.7596	7/16	1100.7903	117.6136
			1/2	1104.4687	117.8100
35 in.	962.1150	109.9560	9/16	1108.1534	118.0063
1/16	965.5542	110.1523	5/8	1111.8441	118.2027
1/8	968.9995	110.3487	1/16	1115.5410	118.3990
3/16	972.4510	110.5450	3/4	1119.2440	118.5954
1/4	975.9085	110.7414	1/16	1122.9532	118.7917
5/16	979.3686	110.9377	1/8	1126.6685	118.9881
3/8	982.8422	111.1341	1/16	1130.3900	119.1844
7/16	986.3180	111.3304			
1/2	989.8003	111.5268	38 in.	1134.1176	119.3808
9/16	993.2097	111.7231	1/16	1137.8513	119.5771
5/8	996.7830	111.9195	1/8	1141.5911	119.7735
1/16	1000.3472	112.1158	3/16	1145.3371	119.9698
3/4	1003.7902	112.3122	1/4	1149.0892	120.1662
1/16	1007.3030	112.5086	5/16	1152.8475	120.3625
1/8	1010.8220	112.7049	3/8	1156.6119	120.5589
1/16	1014.3472	112.9012	7/16	1160.3825	120.7552
			1/2	1164.1591	120.9516
36 in.	1017.8784	113.0976	9/16	1167.9420	121.1479
1/16	1021.4158	113.2939	5/8	1171.7309	121.3443
1/8	1024.9592	113.4903	1/16	1175.5260	121.5406
3/16	1028.5089	113.6866	3/4	1179.3271	121.7370
1/4	1032.0646	113.8830	1/16	1183.1345	121.9333
5/16	1035.6266	114.0793	1/8	1186.9480	122.1297
3/8	1039.1946	114.2757	1/16	1190.7677	122.3260
7/16	1042.7913	114.4720			
1/2	1046.3941	114.6684	39 in.	1194.5934	122.5224
9/16	1049.9581	114.8647	1/16	1198.4253	122.7187
5/8	1053.5281	115.0611	1/8	1202.2633	122.9151
		115.2572	3/16	1206.1075	123.1114
		115.4538	1/4	1209.9577	123.3078
		115.6501	5/16	1213.8142	123.5041
		115.8465	3/8	1217.6768	123.7005
		116.0428	7/16	1221.5455	123.8968

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	1225.4203	124.0932	42 in.	1385.4456	131.9472
9/16	1229.3013	124.2895	1/16	1389.5720	132.1435
5/8	1233.1884	124.4859	1/8	1393.7045	132.3399
11/16	1237.0817	124.6822	3/16	1397.8432	132.5362
3/4	1240.9810	124.8786	1/4	1401.9880	132.7326
13/16	1244.8866	125.0749	5/16	1406.1390	132.9289
7/8	1248.7982	125.2713	3/8	1410.2961	133.1253
15/16	1252.7161	125.4676	7/16	1414.4594	133.3216
			1/2	1418.6287	133.5180
40 in.	1256.6400	125.6640	9/16	1422.8043	133.7143
1/16	1260.5701	125.8603	5/8	1426.9859	133.9107
1/8	1264.5062	126.0567	11/16	1431.1737	134.1070
3/16	1268.4486	126.2530	3/4	1435.3675	134.3034
1/4	1272.3970	126.4494	13/16	1439.5676	134.4997
5/16	1276.3517	126.6457	7/8	1443.7738	134.6961
3/8	1280.3124	126.8421	15/16	1447.9862	134.8924
7/16	1284.2793	127.0384			
1/2	1288.2523	127.2348	43 in.	1452.2046	135.0888
9/16	1292.2315	127.4311	1/16	1456.4292	135.2851
5/8	1296.2168	127.6275	1/8	1460.6599	135.4815
11/16	1300.2082	127.8238	3/16	1464.8968	135.6778
3/4	1304.2057	128.0202	1/4	1469.1397	135.8742
13/16	1308.2095	128.2165	5/16	1473.3839	136.0705
7/8	1312.2193	128.4129	3/8	1477.6342	136.2669
15/16	1316.2353	128.6092	7/16	1481.9006	136.4632
			1/2	1486.1731	136.6596
41 in.	1320.2574	128.8056	9/16	1490.4468	136.8559
1/16	1324.2857	129.0019	5/8	1494.7266	137.0523
1/8	1328.3200	129.1983	11/16	1499.0126	137.2486
3/16	1332.3605	129.3946	3/4	1503.3046	137.4450
1/4	1336.4071	129.5910	13/16	1507.6029	137.6413
5/16	1340.4600	129.7873	7/8	1511.9072	137.8377
3/8	1344.5189	129.9837	15/16	1516.2178	138.0340
7/16	1348.5840	130.1800			
1/2	1352.6551	130.3764	44 in.	1520.5344	138.2304
9/16	1356.7325	130.5727	1/16	1524.8572	138.4267
5/8	1360.8159	130.7691	1/8	1529.1860	138.6231
11/16	1364.9055	130.9654	3/16	1533.5211	138.8194
3/4	1369.0012	131.1618	1/4	1537.8622	139.0158
13/16	1373.1031	131.3581	5/16	1542.2046	139.2121
7/8	1377.2111	131.5545	3/8	1546.5530	139.4085
15/16	1381.3253	131.7508	7/16	1550.9176	139.6048

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
45 in.	1590.4350	141.3720	47 in.	1734.9486	147.6552
	1594.4560	141.5683		1739.5659	147.8515
	1599.2830	141.7647		1744.1893	148.0479
	1603.7162	141.9610		1748.8189	148.2442
	1608.1555	142.1574		1753.4545	148.4406
	1612.5961	142.3537		1758.0914	148.6369
	1617.0427	142.5501		1762.7344	148.8333
	1621.5055	142.7464		1767.3935	149.0296
	1625.9743	142.9428		1772.0587	149.2260
46 in.	1630.4444	143.1391	48 in.	1776.7251	149.4223
	1634.9205	143.3355		1781.3976	149.6187
	1639.4028	143.5318		1786.0763	149.8150
	1643.8912	143.7282		1790.7610	150.0114
	1648.3858	143.9245		1795.4520	150.2077
	1652.8865	144.1209		1800.1490	150.4041
	1657.3934	144.3172		1804.8523	150.6004
	1661.9064	144.5136		1809.5616	150.7968
	1666.4255	144.7099		1814.2551	150.9931
	1670.9507	144.9063		1818.9986	151.1895
	1675.4821	145.1026		1823.7264	151.3858
	1680.0196	145.2990		1828.4602	151.5822
	1684.5583	145.4953		1833.1953	151.7785
	1689.1031	145.6917		1837.9364	151.9749
	1693.6641	145.8880		1842.6937	152.1712
	1698.2311	146.0844		1847.4571	152.3676
	1702.7994	146.2807	49 in.	1852.2167	152.5639
	1707.3737	146.4771		1856.9924	152.7603
	1711.9542	146.6734		1861.7892	152.9566
	1716.5407	146.8698		1868.5521	153.1530
	1721.1335	147.0661		1871.3413	153.3493
	1725.7324	147.2625		1876.1365	153.5457
	9.3375	147.4588		1880.9379	153.7420
				1885.7454	153.9384
				1890.5591	154.1347
				1895.3788	154.3311
				1900.2047	154.5274
				1905.0367	154.7238
				1909.8700	154.9201
				1914.7093	155.1165
				1919.5648	155.3128

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	1924.4263	155.5092	52 in.	2123.7216	163.3632
9/16	1929.2891	155.7055	1/16	2128.8298	163.5595
5/8	1934.1579	155.9019	1/8	2133.9440	163.7559
11/16	1939.0329	156.0982	3/16	2139.0645	163.9522
3/4	1943.9140	156.2946	1/4	2144.1910	164.1486
13/16	1948.8013	156.4909	5/16	2149.3238	164.3449
7/8	1953.6947	156.6873	3/8	2154.4626	164.5413
15/16	1958.0943	156.8836	7/16	2159.6076	164.7376
			1/2	2164.7587	164.9340
50 in.	1963.5000	157.0800	9/16	2169.9160	165.1303
1/16	1968.4118	157.2763	5/8	2175.0794	165.3267
1/8	1973.3297	157.4727	11/16	2180.2489	165.5230
3/16	1978.2525	157.6690	3/4	2185.4245	165.7194
1/4	1983.1840	157.8654	13/16	2190.6064	165.9157
5/16	1988.6154	158.0617	7/8	2195.7943	166.1121
3/8	1993.0529	158.2581	15/16	2200.9884	166.3084
7/16	1998.0066	158.4544			
1/2	2002.9663	158.6508	53 in.	2206.1886	166.5048
9/16	2007.9273	158.8471	1/16	2211.3950	166.7011
5/8	2012.8943	159.0435	1/8	2216.6074	166.8975
11/16	2017.8675	159.2398	3/16	2221.8260	167.0938
3/4	2022.8467	159.4362	1/4	2227.0507	167.2902
13/16	2027.8172	159.6325	5/16	2232.2817	167.4865
7/8	2032.8238	159.8289	3/8	2237.5187	167.6829
15/16	2037.8216	160.0252	7/16	2242.7619	167.8792
			1/2	2248.0111	168.0756
51 in.	2042.8254	160.2216	9/16	2253.2666	168.2719
1/16	2047.8354	160.4179	5/8	2258.5281	168.4683
1/8	2052.8515	160.6143	11/16	2263.7908	168.6646
3/16	2057.8798	160.8106	3/4	2269.0696	168.8610
1/4	2062.9021	161.0070	13/16	2274.3496	169.0573
5/16	2067.9317	161.2033	7/8	2279.6357	169.2537
3/8	2072.9674	161.3997	15/16	2284.9280	169.4500
7/16	2078.0293	161.5960			
1/2	2083.0771	161.7924	54 in.	2290.2264	169.6464
9/16	2088.1362	161.9887	1/16	2295.5309	169.8427
5/8	2093.2014	162.1851	1/8	2300.8415	170.0391
11/16	2098.2678	162.3814	3/16	2306.1583	170.2354
3/4	2103.3502	162.5778	1/4	2311.4812	170.4318
13/16	2108.4339	162.7741	5/16	2316.8163	170.6281
7/8	2113.5236	162.9705	3/8	2322.1455	170.8245
15/16	2118.1196	163.1668	7/16	2327.4819	171.0208

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
55 in.	2375.8350	172.7880	57 in.	2551.7646	179.0712
	2381.2382	172.9843		2557.3637	179.2675
	2386.6465	173.1807		2562.9688	179.4639
	2392.0515	173.3770		2568.5801	179.6602
	2397.4825	173.5734		2574.1975	179.8566
	2402.9098	173.7697		2579.8212	180.0529
	2408.3432	173.9661		2585.4509	180.2493
	2413.7777	174.1624		2591.0869	180.4456
	2419.2283	174.3588		2596.7287	180.6420
56 in.	2424.7026	174.5551	58 in.	2602.3769	180.8383
	2430.1830	174.7515		2608.0311	181.0347
	2435.6246	174.9478		2613.6942	181.2310
	2441.0722	175.1442		2619.3580	181.4274
	2446.5486	175.3405		2625.0307	181.6237
	2452.0310	175.5369		2630.7095	181.8201
	2457.0197	175.7332		2636.3945	182.0164
	2463.0144	175.9296		2642.0856	182.2128
	2468.5153	176.1259		2647.7328	182.4091
	2474.0222	176.3223		2653.4861	182.6055
	2479.5354	176.5186		2659.9565	182.8018
	2485.0546	176.7150		2664.9112	182.9982
	2490.5351	176.9913		2670.6330	183.1945
	2496.1116	177.1077		2676.3609	183.3909
	2501.6493	177.3040		2682.0950	183.5872
	2507.1931	177.5004		2687.8351	183.7836
	2512.7431	177.6967		2693.5814	183.9799
	2518.2992	177.8931		2699.3338	184.1763
	2523.8614	178.0894		2705.0924	184.3726
	2529.4297	178.2858		2710.8571	184.5690
	2535.0043	178.4821		2716.6280	184.7653
	2540.5849	178.6785		2722.4050	184.9617
	2546.1717	178.8748		2728.1882	185.1580
			59 in.	2733.9774	185.3544
				2739.7728	185.5507
				2745.5743	185.7471
				2751.8820	185.9434
				2757.1957	186.1398
				2763.0157	186.3361
				2768.8418	186.5325
				2774.6745	186.7288

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	2780.5123	186.9252	62 in.	3019.0776	194.7792
9/16	2786.3568	187.1215	1/16	3025.1675	194.9755
5/8	2792.2074	187.3179	1/8	3031.2635	195.1719
11/16	2798.0642	187.5142	3/16	3037.3607	195.3682
3/4	2803.9270	187.7106	1/4	3043.4740	195.5646
13/16	2809.7461	187.9069	5/16	3049.6885	195.7609
7/8	2815.6712	188.1033	3/8	3055.7091	195.9573
15/16	2821.5526	188.2996	7/16	3061.8359	196.1536
			1/2	3067.9687	196.3500
60 in.	2827.4400	188.4960	9/16	3074.1578	196.5463
1/16	2833.3336	188.6923	5/8	3080.2529	196.7427
1/8	2839.2332	188.8887	11/16	3086.4042	196.9390
3/16	2845.1391	189.0850	3/4	3092.5615	197.1354
1/4	2851.0510	189.2814	13/16	3098.7251	197.3317
5/16	2856.9692	189.4777	7/8	3104.8948	197.5281
3/8	2862.8934	189.6741	15/16	3111.0707	197.7244
7/16	2868.8223	189.8704			
1/2	2874.7603	189.0668	63 in.	3117.2526	197.9208
9/16	2880.7030	190.2631	1/16	3124.4407	198.1171
5/8	2886.6517	190.4595	1/8	3129.6349	198.3135
11/16	2892.6067	190.6558	3/16	3135.8353	198.5098
3/4	2898.5677	190.8522	1/4	3142.0417	198.7062
13/16	2904.5350	191.0485	5/16	3148.7544	198.9025
7/8	2910.5083	191.2449	3/8	3154.4732	199.0989
15/16	2916.4878	191.4412	7/16	3160.7981	199.2952
			1/2	3166.9291	199.4916
61 in.	2922.4734	191.6376	9/16	3173.1663	199.6879
1/16	2928.4652	191.8339	5/8	3179.4096	199.8843
1/8	2934.4630	192.0303	11/16	3185.6591	200.0806
3/16	2940.4670	192.2266	3/4	3191.9146	200.2770
1/4	2946.4771	192.4230	13/16	3193.1764	200.4733
5/16	2952.4938	192.6193	7/8	3204.4442	200.6697
3/8	2958.5159	192.8157	15/16	3210.7183	200.8660
7/16	2964.5445	193.0120			
1/2	2970.5791	193.2084	64 in.	3216.9984	201.0624
9/16	2976.6200	193.4047	1/16	3223.2847	201.2587
5/8	2982.6669	193.6011	1/8	3229.5770	201.4551
11/16	2988.7200	193.7974	3/16	3235.8746	201.6514
3/4	2994.7792	193.9938	1/4	3242.1782	201.8478
13/16	3000.8423	194.1901	5/16	3248.4936	202.0441
7/8	3006.9161	194.3865	3/8	3254.8080	202.2405
15/16	3017.9938	194.5828	7/16	3261.1311	202.4368

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	3793.6783	218.3412	72 in.	4071.5136	226.1952
1 9/16	3800.5191	218.5375	1 1/16	4078.5853	226.3915
1/8	3807.3369	218.7339	1/8	4085.6631	226.5879
1 1/16	3814.2781	218.9302	1 3/16	4092.7460	226.7842
1/4	3821.0200	219.1266	1/4	4099.8350	226.9806
1 3/16	3827.8708	219.3229	1 5/16	4106.9323	227.1769
3/8	3834.7277	219.5193	3/8	4114.0356	227.3733
1 5/16	3841.5908	219.7156	1 7/16	4121.1442	227.5696
			1/2	4128.2587	227.7660
70 in.	3848.4600	219.9120	1 9/16	4135.3795	227.9623
1 1/16	3855.8353	220.1083	5/8	4142.5064	228.1587
1/8	3862.2167	220.3047	1 1/16	4149.6394	228.3550
1 3/16	3869.1033	220.5010	3/4	4156.7785	228.5514
1/4	3875.9960	220.6974	1 3/16	4163.9239	228.7477
1 5/16	3882.8969	220.8937	1/8	4171.0753	228.9441
3/8	3889.8039	221.0901	1 5/16	4178.2329	229.1404
1 7/16	3896.7211	221.2864			
1/2	3903.6343	221.4828	73 in.	4185.3966	229.3368
1 9/16	3910.5588	221.6791	1 1/16	4192.5665	229.5331
5/8	3917.4893	221.8755	1/8	4199.7424	229.7295
1 1/16	3924.4260	222.0718	1 3/16	4206.9230	229.9258
3/4	3931.3687	222.2682	1/4	4214.1107	230.1222
1 3/16	3938.3177	222.4645	1 5/16	4221.3027	230.3185
1/8	3945.2728	222.6609	3/8	4228.5077	230.5149
1 5/16	3952.2341	222.8572	1 7/16	4235.7109	230.7112
			1/2	4242.9271	230.9076
71 in.	3959.2014	223.0536	1 9/16	4250.1461	231.1039
1 1/16	3966.1749	223.2499	5/8	4257.3711	231.3003
1/8	3973.1545	223.4463	1 1/16	4264.6023	231.4966
1 3/16	3980.1393	223.6426	3/4	4271.8396	231.6930
1/4	3987.1301	223.8390	1 3/16	4279.0831	231.8893
1 5/16	3994.1292	224.0353	1/8	4286.3327	232.0857
3/8	4001.1344	224.2317	1 5/16	4293.5885	232.2820
1 7/16	4008.1447	224.4380			
1/2	4015.1611	224.6244	74 in.	4300.8504	232.4784
1 9/16	4022.1837	224.8207	1 1/16	4308.1185	232.6747
5/8	4029.2124	225.0171	1/8	4315.3926	232.8711
1 1/16	4036.2473	225.2134	1 3/16	4322.1719	233.0674
3/4	4043.2882	225.4098	1/4	4329.9572	233.2638
1 3/16	4050.3354	225.6061	1 5/16	4337.2508	233.4601
1/8	4057.3886	225.8025	3/8	4344.5505	233.6565
1 5/16	4064.4481	225.9988	1 7/16	4351.8551	233.8528

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
½	4963.9243	249.7572	82 in.	5281.0296	257.6112
1/16	4971.7319	249.9535	1/16	5289.0781	257.8075
⅛	4979.5456	250.1499	⅛	5297.1426	258.0039
3/16	4987.3663	250.3462	3/16	5305.2073	258.2002
¼	4995.1930	250.5426	¼	5313.2780	258.3966
5/16	5003.0316	250.7389	5/16	5321.3570	258.5929
⅜	5010.8642	250.9353	⅜	5329.4421	258.7893
7/16	5018.7091	251.1316	7/16	5337.5324	258.9856
			½	5345.6287	259.1820
80 in.	5026.5600	251.3280	9/16	5353.7809	259.3783
1/16	5034.4171	251.5243	⅝	5361.8391	259.5747
⅛	5042.2803	251.7207	11/16	5369.9543	259.7710
3/16	5050.1486	251.9170	¾	5378.0755	259.9674
¼	5058.0230	252.1134	13/16	5386.2026	260.1637
5/16	5065.9027	252.3097	⅞	5394.3358	260.3601
⅜	5073.7944	252.5061	15/16	5402.4552	260.5564
7/16	5081.6883	252.7024			
½	5089.5883	252.8988	83 in.	5410.6206	260.7528
9/16	5097.4941	253.0951	1/16	5418.7722	260.9491
⅝	5105.4060	253.2915	⅛	5426.9299	261.1455
11/16	5113.8248	253.4878	3/16	5435.0928	261.3418
¾	5121.2497	253.6842	¼	5443.2617	261.5382
13/16	5129.1855	253.8805	5/16	5451.4389	261.7345
⅞	5137.1173	254.0769	⅜	5459.6222	261.9309
15/16	5145.0603	254.2732	7/16	5467.8106	262.1272
			½	5476.0051	262.3236
81 in.	5153.0094	254.4696	9/16	5484.2054	262.5199
1/16	5160.9647	254.6659	⅝	5492.4118	262.7163
⅛	5168.9260	254.8623	11/16	5500.6252	262.9126
3/16	5176.8925	255.0586	¾	5508.8446	263.1090
¼	5184.8651	255.2550	13/16	5517.0699	263.3053
5/16	5192.8460	255.4513	⅞	5525.3012	263.5017
⅜	5200.8329	255.6477	15/16	5533.5388	263.6980
7/16	5208.8250	255.8440			
½	5216.8231	256.0404	84 in.	5541.7824	263.8944
9/16	5224.8271	256.2367	1/16	5550.0322	264.0907
⅝	5232.8371	256.4331	⅛	5558.2881	264.2871
11/16	5240.8568	256.6294	3/16	5566.5491	264.4834
¾	5248.8772	256.8258	¼	5574.8162	264.6798
13/16	5256.9061	257.0221	5/16	5583.0916	264.8761
⅞	5264.9411	257.2105	⅜	5591.3730	265.0725
15/16	5272.9828	257.4148	7/16	5599.6596	265.2688

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	6291.2503	281.1732	92 in.	6647.6258	289.0272
1/16	6300.0397	281.3695	1/16	6656.6609	289.2235
1/8	6308.8351	281.5659	1/8	6665.7021	289 4199
1 1/16	6317.6375	281.7622	3/16	6674.7485	289.6162
3/4	6326.4460	281.9586	1/4	6683.8010	289.8125
1 3/16	6335.2603	282.1549	5/16	6692.8618	290.0089
1/8	6344.0807	282.3513	3/8	6701.9286	290.2053
1 5/16	6352.9073	282.5476	7/16	6711.5001	290.4016
			1/2	6720.0787	290.5980
90 in.	6361.7400	282.7440	9/16	6729.6628	290.7943
1/16	6370.5789	282.9403	5/8	6738.2530	290.9907
1/8	6379.4238	283.1367	1 1/16	6747.3497	291.1870
3/16	6388.7739	283.3330	3/4	6756.4525	291.3834
1/4	6397.1300	283.5294	1 3/16	6765.5614	291.5797
5/16	6405.9944	283.7257	1/8	6774.6763	291.7761
3/8	6414.8649	283.9221	1 5/16	6783.7975	291.9724
7/16	6423.7906	284.1184			
1/2	6432.6223	284.3148	93 in.	6792.9248	292.1688
9/16	6441.5101	284.5111	1/16	6802.0581	292.3651
5/8	6450.4039	284.7075	1/8	6811.1974	292.5615
1 1/16	6459.3043	284.9038	3/16	6820.3420	292.7578
3/4	6468.2107	285.1002	1/4	6829.4927	292.9542
1 3/16	6477.1232	285.2965	5/16	6838.6517	293.1505
1/8	6486.0418	285.4929	3/8	6847.8167	293.3469
1 5/16	6494.9566	285.6892	7/16	6856.9869	293.5432
			1/2	6866.1631	293.7396
91 in.	6503.8974	285.8856	9/16	6875.3454	293.9359
1/16	6512.8344	286.0819	5/8	6884.5338	294.1323
1/8	6521.7775	286.2783	1 1/16	6893.7337	294.3286
3/16	6530.7258	286.4746	3/4	6902.9296	294.5250
1/4	6539.6801	286.6710	1 3/16	6912.1366	294.7213
5/16	6548.6427	286.8673	1/8	6921.3497	294.9177
3/8	6557.6114	287.0637	1 5/16	6930.5691	295.1140
7/16	6566.5857	287.2600			
1/2	6573.5651	287.4564	94 in.	6939.7946	295.3104
9/16	6584.5511	287.6527	1/16	6949.5261	295.5067
5/8	6593.5431	287.8491	1/8	6958.2636	295.7031
1 1/16	6602.5443	288.0454	3/16	6968.0064	295.8994
3/4	6611.5462	288.2418	1/4	6976.7552	296.0958
1 3/16	6620.5569	288.4381	5/16	6986.0123	296.2921
1/8	6629.5736	288.6345	3/8	6995.2755	296.4885
1 5/16	6638.5967	288.8388	7/16	7004.5439	296.6848

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	7013.8183	296.8812	97 in.	7389.8288	304.7352
9/16	7023.0988	297.0775	1/16	7399.3548	304.9315
5/8	7032.3853	297.2739	1/8	7408.8868	305.1279
11/16	7041.6784	297.4702	3/16	7418.6241	305.3242
3/4	7050.9775	297.6666	1/4	7427.9675	305 5206
13/16	7060.2827	297.8629	5/16	7437.5192	305.7169
7/8	7069.5940	298.0593	3/8	7447.0769	305.9133
15/16	7075.9116	298.2556	7/16	7456.6398	306.1096
			1/2	7466.2087	306.3060
95 in.	7088.2352	298.4520	9/16	7475.7837	306.5023
1/16	7097.5738	298.6483	5/8	7485.3648	306.6987
1/8	7106.9005	298.8447	11/16	7494.9524	306.8950
3/16	7116.7415	299.0400	3/4	7504.5460	307 0914
1/4	7125.5885	299.2374	13/16	7514.1457	307.2877
5/16	7134.9443	299.4337	7/8	7523.7515	307.4841
3/8	7144.3052	299.6301	15/16	7533.3636	307.6804
7/16	7153.6717	299.8264			
1/2	7163.0443	300.0228	98 in.	7542.9818	307.8768
9/16	7172.4230	300.2191	1/16	7552.6060	308.0731
5/8	7181.8077	300.4155	1/8	7562.2362	308.2695
11/16	7191.1989	300.6118	3/16	7575.8717	308.4658
3/4	7200.5962	300.8082	1/4	7581.5132	308.6622
13/16	7209.9096	301.0045	5/16	7591.1630	308.8585
7/8	7219.4090	301.2009	3/8	7600.8189	309.0549
15/16	7228.8248	301.3972	7/16	7610.4800	309.2512
			1/2	7620.1471	309.4476
96 in.	7238.2466	301.5936	9/16	7629.8203	309.6439
1/16	7247.6741	301.7899	5/8	7639.4995	309.8403
1/8	7257.1083	301.9863	11/16	7649.1853	310.0366
3/16	7266.5474	302.1826	3/4	7658.8771	310.2330
1/4	7275.9926	302.3790	13/16	7668.5750	310.4293
5/16	7285.4461	302.5753	7/8	7678.2790	310.6257
3/8	7294.9056	302.7717	15/16	7687.9893	310.8220
7/16	7304.3703	302.9680			
1/2	7313.8411	303.1644	99 in.	7697.7056	311.0184
		303.3607	1/16	7707.4279	311.2147
		303.5571	1/8	7717.1563	311.4111
		303.7534	3/16	7726.8900	311.6074
		303.9498	1/4	7736.6297	311.8038
		304.1461	5/16	7746.3777	312.0001
		304.3425	3/8	7756.1318	312.1965
		304.5388	7/16	7765.8910	312.3928

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
½	7775.6563	312.5892	½	8413.4008	325.1556
9/16	7785.4277	312.7855	¾	8454.0944	325.9410
⅝	7795.2051	312.9819			
11/16	7804.9890	313.0782	104 in.	8494.8864	326.7264
¾	7814.7790	313.3746	¼	8535.7760	327.5118
13/16	7824.5751	313.5709	½	8576.7640	328.2972
⅞	7834.3772	313.7673	¾	8617.8504	329.0826
15/16	7844.1856	313.9636			
			105 in.	8659.0348	329.8680
100 in.	7854.0000	314.1600	¼	8700.3176	330.6534
¼	7893.3199	314.9454	½	8741.6980	331.4388
½	7932.7360	315.7308	¾	8783.1772	332.2242
¾	7972.2120	316.5162			
			106 in.	8824.7544	333.0096
101 in.	8011.8652	317.3016	½	8908.2028	334.5804
¼	8051.5772	318.0870			
½	8091.3870	318.8724	107 in.	8992.0444	336.1512
¾	8131.2953	319.6578	½	9076.2784	337.7220
102 in.	8171.3016	320.4432	108 in.	9160.9056	339.2928
¼	8211.4060	321.2286	½	9245.9248	340.8636
½	8251.6084	322.0140			
¾	8291.8696	322.7994	109 in.	9331.3372	342.4344
			½	9417.1420	344.0052
103 in.	8332.3085	323.5848			
¼	8372.8056	324.3702	110 in.	9503.3400	345.5760

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.
4	42.2367	23 $0\frac{3}{8}$	6	86.5903	32 $11\frac{3}{4}$
5	43.2022	23 $2\frac{1}{8}$	7	87.9697	33 $2\frac{7}{8}$
6	44.1787	23 $6\frac{3}{4}$	8	89.3608	33 $6\frac{1}{8}$
7	45.1656	23 11	9	90.7627	33 $9\frac{1}{4}$
8	46.1638	24 $1\frac{1}{8}$	10	92.1749	34 $0\frac{3}{8}$
9	47.1730	24 $4\frac{1}{8}$	11	93.5986	34 $3\frac{1}{2}$
10	48.1926	24 $7\frac{1}{4}$	11 ft.	95.0334	34 $6\frac{5}{8}$
11	49.2236	24 $10\frac{1}{8}$	1	96.4783	34 $9\frac{3}{4}$
3 ft.	50.2656	25 $1\frac{1}{2}$	2	97.9347	35 $0\frac{7}{8}$
1	51.3178	25 $4\frac{5}{8}$	3	99.4021	35 $4\frac{1}{8}$
2	52.3816	25 $7\frac{7}{8}$	4	100.8797	35 $7\frac{1}{4}$
3	53.4562	25 11	5	102.3689	35 $10\frac{5}{8}$
4	54.5412	26 $2\frac{1}{8}$	6	103.8691	36 $1\frac{1}{2}$
5	55.6377	26 $5\frac{1}{4}$	7	105.3794	36 $4\frac{5}{8}$
6	56.7451	26 $8\frac{3}{8}$	8	106.9013	36 $7\frac{3}{4}$
7	57.8628	26 $11\frac{1}{2}$	9	108.4342	36 $10\frac{7}{8}$
8	58.9920	27 $2\frac{3}{4}$	10	109.9772	37 $2\frac{3}{4}$
9	60.1321	27 $5\frac{3}{4}$	11	111.5319	37 $5\frac{1}{4}$
10	61.2826	27 9	12 ft.	113,0976	37 $8\frac{3}{8}$
11	62.4445	28 $0\frac{1}{2}$	1	114.6732	37 $11\frac{1}{2}$
0 ft.	63.6174	28 $3\frac{1}{4}$	2	116.2607	38 $2\frac{5}{8}$
1	64.8006	28 $6\frac{3}{8}$	3	117.8590	38 $5\frac{3}{4}$
2	65.9951	28 $9\frac{1}{2}$	4	119.4674	38 $8\frac{7}{8}$
3	67.2007	29 $0\frac{5}{8}$	5	121.0876	39 0
4	68.4166	29 $3\frac{3}{4}$	6	122.7187	39 $3\frac{1}{4}$
5	69.6440	29 7	7	124.3598	39 $6\frac{3}{8}$
6	70.8823	29 $10\frac{1}{8}$	8	126.0127	39 $9\frac{1}{2}$
7	72.1309	30 $1\frac{1}{4}$	9	127.6765	40 $0\frac{5}{8}$
8	73.3910	30 $4\frac{3}{8}$	10	129.3504	40 $3\frac{1}{4}$
9	74.6620	30 $7\frac{1}{2}$	11	131.0360	40 $6\frac{7}{8}$
10	75.9433	30 $11\frac{5}{8}$	13 ft.	132.7326	40 10
11	77.2362	31 $1\frac{3}{4}$	1	134.4391	41 $1\frac{1}{8}$
0 ft.	78.5400	31 5	2	136.1574	41 $4\frac{3}{8}$
1	79.8540	31 $8\frac{1}{8}$	3	137.8867	41 $7\frac{1}{2}$
2	81.1795	31 $11\frac{1}{4}$	4	139.6260	41 $10\frac{5}{8}$
3	82.5160	32 $2\frac{3}{8}$	5	141.3771	42 $1\frac{3}{8}$
4	83.8627	32 $5\frac{1}{2}$	6	143.1391	42 $4\frac{1}{8}$
5	85.2211	32 $8\frac{5}{8}$	7	144.9111	42 8

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
20 ft.	314.1600	62 9⅞	2	421.5192	72 9⅜
1	316.7824	63 1⅛	3	424.5577	73 0½
2	319.4173	63 4¼	4	427.6055	73 3⅝
3	322.0630	63 7⅜	5	430.6658	73 6¾
4	324.7182	63 11½	6	433.7371	73 9⅞
5	327.3858	64 1⅝	7	436.8175	74 1
6	330.0643	64 4¾	8	439.9106	74 4⅛
7	332.7522	64 7⅞	9	443.0146	74 7¼
8	335.4525	64 11	10	446.1278	74 10⅜
9	338.1637	65 2¼	11	449.2536	75 1⅝
10	340.8844	65 5⅜	24 ft.	452.3904	75 4¾
11	343.6174	65 8¼	1	455.5362	75 7⅞
21 ft.	346.3614	65 11⅜	2	458.6948	75 11
1	349.1147	66 2¾	3	461.8642	76 2⅛
2	351.8804	66 5⅞	4	465.0428	76 5¼
3	354.6571	66 9	5	468.2341	76 8½
4	357.4432	67 0¼	6	471.4363	76 11⅝
5	360.2417	67 3⅜	7	474.6476	77 2¾
6	363.0511	67 6½	8	477.8716	77 5⅞
7	365.8698	67 9⅝	9	481.1065	77 9
8	368.7011	68 0¾	10	484.3506	78 0⅛
9	371.5432	68 3⅞	11	487.6073	78 3¼
10	374.3947	68 7	25 ft.	490.8750	78 6⅜
11	377.2587	68 10¼	1	494.1516	78 9½
22 ft.	380.1336	69 1⅜	2	497.4411	79 0⅝
1	383.0177	69 4½	3	500.7415	79 3⅞
2	385.9144	69 7⅝	4	504.0510	79 7⅛
3	388.8220	69 10¾	5	507.3732	79 11⅛
4	391.7389	70 1⅞	6	510.7063	80 1¼
5	394.6683	70 5	7	514.0484	80 4⅜
6	397.6087	70 8¼	8	517.4034	80 7⅝
7	400.5583	70 11⅛	9	520.7692	80 10¾
8	403.5204	71 2⅛	10	524.1441	81 1⅞
9	406.4935	71 5⅜	11	527.5318	81 5
10	409.4759	71 8¾	26 ft.	530.9304	81 8⅛
11	412.4707	71 11⅞	1	534.3379	81 11¼
23 ft.	415.4766	72 3	2	537.7583	82 2⅜
1	418.4915	72 6⅛	3	541.1896	82 5¼

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
4	544.6299	82 8⅝	6	683.4943	92 8⅝
5	548.0830	82 11⅞	7	687.3598	92 11⅞
6	551.5471	83 3	8	691.2385	93 2⅛
7	555.0201	83 6⅛	9	695.1280	93 5⅛
8	558.5059	83 9¼	10	699.0263	93 8⅛
9	562.0027	84 0⅛	11	702.9377	93 11⅛
10	565.5084	84 3⅛	30 ft.	706.8600	94 2⅛
11	569.0270	84 6⅝	1	710.7909	94 6
27 ft.	572.5566	84 9⅞	2	714.7350	94 9¼
1	576.0949	85 1	3	718.6900	95 0⅛
2	579.6463	85 4¼	4	722.6537	95 3⅛
3	583.2085	85 8¼	5	726.6305	95 6⅛
4	586.7796	85 11⅛	6	730.6183	95 9⅛
5	590.3637	86 1⅛	7	734.6147	96 0⅛
6	593.9587	86 4⅛	8	738.6242	96 4
7	597.5625	86 7⅛	9	742.6447	96 7¼
8	601.1793	86 11	10	746.6738	96 10⅛
9	604.8070	87 2⅛	11	750.7161	97 1⅛
10	608.4436	87 5¼	31 ft.	754.7694	97 4⅛
11	612.0931	87 8⅝	1	758.8311	97 7⅛
28 ft.	615.7536	87 11⅛	2	762.9062	97 10⅛
1	619.4228	88 2⅛	3	766.9921	98 2
2	623.1050	88 5⅛	4	771.0866	98 5⅛
3	626.7982	88 9	5	775.1944	98 8⅛
4	630.5002	89 0⅛	6	779.3131	98 11⅛
5	634.2152	89 3¼	7	783.4403	99 2⅛
6	637.9411	89 6⅝	8	787.5808	99 5¾
7	641.6758	89 9⅛	9	791.7322	99 8⅞
8	645.4235	90 0⅝	10	795.8922	100 0
9	649.1821	90 3¾	11	800.0654	100 3⅛
10	652.9495	90 6⅞	32 ft.	804.2496	100 6⅛
11	656.7300	90 11⅛	1	808.4422	100 9⅛
29 ft.	660.5214	91 1¼	2	812.6481	101 0⅛
1	664.3214	91 4⅝	3	816.8650	101 3¾
2	668.1346	91 7⅛	4	821.0904	101 6⅞
3	671.9587	91 10⅝	5	825.3291	101 10
4	675.7915	92 1¾	6	829.5787	102 1⅛
	375	92 4⅞	7	833.8368	102 4⅛

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
8	838.1082	102 7½	10	1008.4736	112 6⅞
9	842.3905	102 10⅜	11	1013.1705	112 10
10	846.6813	103 1¼	36 ft.	1017.8784	113 1⅛
11	850.9855	103 4⅞	1	1022.5944	113 4¼
33 ft.	855.3006	103 8	2	1027.3240	113 7⅜
1	859.6240	103 11⅛	3	1032.0646	113 10⅜
2	863.9609	104 2¼	4	1036.8134	114 1¼
3	868.3087	104 5⅜	5	1041.5758	114 4⅝
4	872.6649	104 8⅜	6	1046.3491	114 8
5	877.0346	104 11¼	7	1051.1306	114 11⅛
6	881.4151	105 2⅛	8	1055.9257	115 2¼
7	885.8040	105 6	9	1060.7317	115 5⅜
8	890.2064	105 9⅛	10	1065.5459	115 9¼
9	894.6196	106 0¼	11	1070.3738	115 11⅜
10	899.0413	106 3⅜	37 ft.	1075.2126	116 2⅛
11	903.4763	106 6⅜	1	1080.0594	116 6
34 ft.	907.9224	106 9¼	2	1084.9201	116 9⅛
1	912.3767	107 0⅛	3	1089.7915	117 0¼
2	916.8445	107 4	4	1094.6711	117 3½
3	921.3232	107 7⅛	5	1099.5644	117 6⅝
4	925.8103	107 10¼	6	1104.4687	117 9⅝
5	930.3108	108 1⅜	7	1109.3810	118 0¾
6	934.8223	108 4⅜	8	1114.3071	118 4
7	939.3421	108 7¼	9	1119.2440	118 7⅛
8	943.8753	108 10⅛	10	1124.1891	118 10¼
9	948.4195	109 2	11	1129.1478	119 1⅜
10	952.9720	109 5⅛	38 ft.	1134.1176	119 4½
11	957.5380	109 8¼	1	1139.0953	119 7⅝
35 ft.	962.1150	109 11⅜	2	1144.0868	119 10¾
1	966.7001	110 2⅜	3	1149.0892	120 2
2	971.2989	110 5¼	4	1154.0997	120 5⅛
3	975.9085	110 8⅛	5	1159.1239	120 8⅜
4	980.5264	111 0	6	1164.1591	120 11⅜
5	985.1579	111 3⅛	7	1169.2023	121 2¼
6	989.8003	111 6¼	8	1174.2592	121 5⅜
7	994.4509	111 9⅜	9	1179.3271	121 8¾
8	999.1151	112 0½	10	1184.4030	121 11⅛
9	1003.7902	112 3¾	11	1189.4927	122 3⅜

APPENDIX.

Barometer Notes, etc.—Continued.

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
4	1614.0819	142 5	9	1790.7610	150 0⅛
5	1620.0226	142 8⅛	10	1797.0145	150 3¼
6	1625.9743	142 11¼	11	1803.2826	150 6⅜
7	1631.9334	143 2⅜	48 ft.	1809.5616	150 9½
8	1637.9068	143 5½	1	1815.8477	151 0⅛
9	1643.8912	143 8¾	2	1822.1485	151 3¾
10	1649.8831	143 11⅞	3	1828.4602	151 6⅞
11	1655.8892	144 3	4	1834.7791	151 10⅛
46 ft.	1661.9064	144 6⅛	5	1841.1127	152 1¼
1	1667.9308	144 9¼	6	1847.4571	152 4⅜
2	1673.9698	145 0⅜	7	1853.8087	152 7½
3	1680.0196	145 3½	8	1860.1750	152 10⅝
4	1686.0769	145 6⅝	9	1866.5521	153 1⅞
5	1692.1485	145 9⅞	10	1872.9365	153 4⅞
6	1698.2311	146 1⅛	11	1879.3355	153 8⅛
7	1704.3210	146 4⅜	49 ft.	1885.7454	153 11¼
8	1710.4254	146 7¼	1	1892.1724	154 2⅜
9	1716.5407	146 10⅜	2	1898.5041	154 5½
10	1722.6634	147 1½	3	1905.0367	154 8⅝
11	1728.8005	147 4⅝	4	1911.4965	154 11⅞
47 ft.	1734.9486	147 7¾	5	1917.9609	155 2⅞
1	1741.1039	147 11	6	1924.4263	155 6
2	1747.2738	148 2⅛	7	1930.9188	155 9¼
3	1753.4545	148 5¼	8	1937.3159	156 0⅛
4	1759.6426	148 8⅜	9	1943.9140	156 3½
5	1765.8452	148 11½	10	1950.4392	156 6⅝
6	1772.0587	149 2⅝	11	1956.9691	156 9¾
7	1778.2795	149 5⅞	50 ft.	1963.5000	157 0⅛
8	1784.5148	149 8⅛			

Table exhibiting the Temperatures and Volumes of Steam generated under different pressures.

Pressure in lbs. per square inch, atmospheric pressure included.	Temperature in degrees of Fahrenheit.	Volumes of steam compared with the volume of water.	Cubic inches of water in a cubic foot of steam.	Pressure in lbs. per square inch, atmospheric pressure included.	Temperature in degrees of Fahrenheit.	Volumes of steam compared with the volume of water.	Cubic inches of water in a cubic foot of steam.
15	213·0	1669	1·035	48	279.7	573	3·015
16	216·4	1572	1·099	49	281·0	562	3·074
17	219·6	1487	1·162	50	282·3	552	3·130
18	222·6	1410	1·226	51	283·6	542	3·188
19	225·6	1342	1·287	52	284·8	532	3·248
20	228·3	1280	1·350	53	286·0	523	3·304
21	231·0	1224	1·411	54	287·2	514	3·361
22	233·6	1172	1·474	55	288·4	506	3·415
23	236·1	1125	1·536	56	289·6	498	3·469
24	238·4	1082	1·597	57	290·7	490	3·526
25	240·7	1042	1·658	58	291·9	482	3·585
26	243·0	1005	1·719	59	293·0	474	3·645
27	245·1	971	1·779	60	294·1	467	3·700
28	247·2	939	1·840	61	294·9	460	3·756
29	249·2	909	1·910	62	295·9	453	3·814
30	251·2	882	1·959	63	297·0	447	3·865
31	253·1	855	2·021	64	298·1	440	3·927
32	255·0	831	2·079	65	299·1	434	3·981
33	256·8	808	2·138	66	300·1	428	4·037
34	258·6	786	2·198	67	301·2	422	4·094
35	260·3	765	2·258	68	302·2	417	4·143
36	262·0	746	2·316	69	303·2	411	4·204
37	263·7	727	2·376	70	304·2	406	4·256
38	265·3	710	2·433	71	305·1	401	4·309
39	266·9	693	2·493	72	306·1	396	4·363
40	268·4	677	2·552	73	307·1	391	4·419
41	269·9	662	2·610	74	308·0	386	4·476
42	271·4	647	2·670	75	308·9	381	4·535
43	272·9	634	2·725	76	309·9	377	4·583
44	274·3	620	2·787	77	310·8	372	4·645
45	275·7	608	2·842	78	311·7	368	4·695
46	277·1	596	2·899	79	312·6	364	4·747
47	278·4	584	2·958	80	313·5	359	4 812

Table by which to ascertain the amount of lap necessary on the steam side of a slide-valve to cut the steam off at various fractional parts of the stroke

To cut the steam off, after the piston has passed through						
$\frac{1}{2}$	$\frac{7}{12}$	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{5}{6}$	$\frac{7}{8}$	$\frac{11}{12}$
of its stroke. Multiply the given stroke of the valve by						
·354	·323	·289	·250	·204	·177	144
and the product is the lap of the valve in terms of the stroke.						

Example.—Required the lap necessary to cut the steam off at the end of five-sixths of the stroke, the stroke of the valve being twelve inches, and without lead. $204 \times 12 = 2{\cdot}448$ inches.

As lead is not taken into account because of different quantities being required to different applications of the steam-engine, subtract from the lap half the lead; the remainder is the lap required. Thus, suppose the lead equal $·25 \div 2 = ·125$ and $2{\cdot}448 - ·125 = 2{\cdot}323$ inches, the lap with one-fourth inch of lead as given.

Table by which to find the relative state of Piston and Exhaust after Expansion.

	Steam cut off at 1-3d from the end of the stroke.		Steam cut off at 1-4th from the end of the stroke.		Steam cut off at 1-6th from the end of the stroke		Steam cut off at 1-8th from the end of the stroke.	
Cover on the exhausting side of the valve in parts of the length of its stroke.	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)
1-8th	·178	·033	·143	·019	·109	·008	·093	·004
1-16th	·130	·060	·100	·040	·171	·022	·058	·015
1-32d	·113	·073	·085	·051	·058	·033	·043	·023
0	·029	·092	·067	·067	·043	·043	·038	·033

Example from the Table.—Suppose an engine with a stroke of six feet, or 72 inches, and the steam cut off when the piston is one-third from the end of its stroke, the cover on the exhaust side of the valve being 1-32d of its stroke, the relative positions will be the following:—

In a line with 1-32d and under 1-3d is ·113 and ·073; therefore $·113 \times 72 = 8·136$ inches the piston is from the end of the stroke, when the exhausting-port before the piston is shut, and $·073 \times 72 = 5·256$ inches the piston is from the end of the stroke, when the exhausting-port behind it is open

Table of Nominal Velocities for the Pistons of Steam-engines, with given Length of Stroke.

Steamboat Condensing Engines.			Marine Engines.			Short Cylinder, or Non-condensing Engines.		
Length of Stroke in Feet and Inches.	Number per Minute.	Velocity in Feet per Minute.	Length of Stroke in Feet and Inches.	Number per Minute.	Velocity in Feet per Minute.	Length of Stroke in Feet and Inches.	Number per Minute.	Velocity in Feet per Minute.
1 9	46	161	2 0	42	168	1 0	72	144
2 0	42	168	2 3	38½	177½	1 3	70	175
2 3	38	171	2 6	35	180	1 6	62	186
2 6	35	175	2 9	33	192	1 9	53	198½
2 9	32	176	3 3	30½	193½	2 0	50	200
3 0	30	180	3 6	27½	192½	2 3	46	207
3 3	28½	183½	3 9	25½	196	2 6	42½	213½
3 6	27	189	4 3	23½	199½	2 9	39½	217½
3 9	26	195	4 6	22½	202½	3 0	37	222
4 0	23	200	4 9	21½	204½	3 3	35	228½
4 3	24	204	5 0	21	210	3 6	33	231
4 6	23	207	5 6	19½	214½	3 9	31	232½
5 0	21½	215	5 9	19	218½	4 0	29½	236
5 6	20	220	6 0	18½	222	4 6	27	243
6 0	19	228	6 6	17½	224½	5 0	24½	247½
7 0	17½	245	7 0	16½	231	5 6	23	253
8 0	16	256	7 6	15½	232½	6 0	22	264

Table of Decimal Equivalents to Fractional Parts of Lineal Measures.

One inch, the integer or whole number.

·9375 =	15/16	and 1/16	·5625 =	9/16	and 1/16	·25 =	1/4
·875 =	7/8		·5 =	1/2		·1875 =	3/16 and 1/16
·8125 =	13/16	and 1/16	·4375 =	7/16	and 1/16	·125 =	1/8
·75 =	3/4		·375 =	3/8		·0625 =	1/16
·6875 =	11/16	and 1/16	·3152 =	5/16	and 1/16	·03125 =	1/32
·625 =	5/8						

One foot, or 12 inches the integer.

·9166 =	11 inches.	·4166 =	5 inches.	·0625 =	3/4	of 1 inch.
·8338 =	10 "	·3333 =	4 "	·05208 =	5/8	"
·75 =	9 "	·25 =	3 "	·04166 =	1/2	"
·6666 =	8 "	·1666 =	2 "	·03125 =	3/8	"
·5833 =	7 "	·0833 =	1 "	·02083 =	1/4	"
·5 =	6 "	·07291 =	7/8 "	·1041 =	1/8	"

Table of Squares, Cubes, Square and Cube Roots of Numbers.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
1	1	1	1·0000000	1·0000000
8	4	2	1·4142136	1·2599210
27	9	3	1·7320508	1·4422496
64	16	4	2·0000000	1·5874011
125	25	5	2·2360680	1·7099759
216	36	6	2·4494897	1·8171216
343	49	7	2·6457513	1·9129312
512	64	8	2·8284271	2·0000000
729	81	9	3·0000000	2·0800837
1000	100	10	3·1622777	2·1544347
1331	121	11	3·3166248	2·2239801
1728	144	12	3·4641016	2·2894286
2197	169	13	3·6055513	2·3513347
2744	196	14	3·7416574	2·4101422
3375	225	15	3·8729833	2·4262121
4096	256	16	4·0000000	2·5198421
4913	289	17	4·1231056	2·6712816
5832	324	18	4·2426407	2·6207417
6859	361	19	4·3588989	2·6684016
8000	400	20	4·4721360	2·7144177
9261	441	21	4·5825757	2·7589243
10648	484	22	4·6904158	2·8020393
12167	529	23	4·7958315	2·8438670
13824	576	24	4·8989795	2·8844991
15625	625	25	5·0000000	2·9240177
17576	676	26	5·0990195	2·9624960
19683	729	27	5·1961524	3·0000000
21952	784	28	5·2915026	3·0365889
24389	841	29	5·3851648	3·0723168
27011	900	30	5·4772256	3·1072325
29791	961	31	5·5677644	3·1413806
32768	1024	32	5·6568542	3·1748021
35937	1089	33	5·7445626	3·2075343
39304	1156	34	5·8309519	3·2396118

Table of Squares, Cubes, &c.—Continued.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
2571353	18769	137	11·7046999	5·1550367
2628072	19044	138	11·7473444	5·1676493
2685619	19321	139	11·7898261	5·1801015
2744000	19600	140	11·8321596	5·1924941
2803221	19881	141	11·8743421	5·2048279
2863288	20164	142	11·9163753	5·2171034
2924207	20449	143	11·9582607	5·2293315
2985984	20736	144	12·0000000	5·2414828
3048625	21025	145	12·0415946	5·2535879
3112136	21316	146	12·0830460	5·2656374
3176523	21609	147	12·1243557	5·2776321
3241792	21904	148	12·1655251	5·2895725
3307949	22211	149	12·2065556	5·3014592
3375000	22500	150	12·2474487	5·3132928
3442951	22801	151	12·2882057	5·3250740
3511008	23104	152	12·3288280	5·3368033
3581577	23409	153	12·3693169	5·3484812
3652264	23716	154	12·4096736	5·3601084
3723875	24025	155	12·4498996	5·3716854
3796416	24336	156	12·4899960	5·3832126
3869893	24649	157	12·5299641	5·3946907
3944312	24964	158	12·5698051	5·4061202
4019679	25281	159	12·6095202	5·4178015
4096000	25600	160	12·6491106	5·4258352
4173281	25921	161	12·6885775	5·4401218
4251528	26244	162	12·7279221	5·4513618
4330747	26569	163	12·7671453	5·4625556
4410944	26896	164	12·8062485	5·4737037
4492125	27225	165	12·8432326	5·4848066
4574296	27556	166	12·8840987	5·4958647
4657463	27889	167	12·9228480	5·5068784
4741632	28224	168	12·9614814	5·5178484
4826809	28561	169	13·0000000	5·5287748
4913000	28900	170	13·0384048	5·5396583

Table of Hyperbolic Logarithms.

ıms.	Number.	Logarithms.	Number.	Logarithms.
503	1·40	·3364722	1·79	·5822156
026	1·41	·3435897	1·80	·5877866
588	1·42	·3506568	1·81	·5933268
207	1·43	·3576744	1·82	·5988365
902	1·44	·3646431	1·83	6043159
689	1·45	·3715635	1·84	·6097655
586	1·46	·3784364	1·85	·6151856
610	1·47	·3852624	1·86	·6205764
777	1·48	·3920420	1·87	·6259384
102	1·49	·3987761	1·88	·6312717
600	1·50	·4054651	1·89	·6365768
287	1·51	·4121096	1·90	·6418538
176	1·52	·4187103	1·91	·6471032
283	1·53	·4252677	1·92	·6523251
619	1·54	·4317824	1·93	·6575200
200	1·55	·4382549	1·94	·6626879
037	1·56	·4446858	1·95	·6678293
144	1·57	·4510756	1·96	·6729444
533	1·58	·4574248	1·97	·6780335
215	1·59	·4637340	1·98	·6830968
030	1·60	·4700036	1·99	·6881346
508	1·61	·4762341	2·00	·6931472
141	1·62	·4824261	2·01	·6981347
113	1·63	·4885800	2·02	·7030974
435	1·64	·4946962	2·03	·7080357
117	1·65	·5007752	2·04	·7129497
	1·66	·5068175	2·05	·7178397
	67	·5128236	2·06	·7227059
	8	·5187937	2·07	·7275485
	9	·5247285	2·08	·7323678
	70	·5306282	2·09	·7316470
	71	·5364933	2·10	·7419373
	72	·5423242	2·11	·7466879
	73	·5481214	2·12	·7514160
	1·74	·5538851	2·13	·7561219
	1·75	·5596157	2·14	·7608058
	1·76	·5653138	2·15	·7654678
	1·77	·5709795	2·16	·7701082
	1·78	·5766133	2·17	·7747271

Table of Hyperbolic Logarithms—Continued.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
3·35	1·2089603	3·74	1·3190856	4·13	1·4182774
3·36	1·2119409	3·75	1·3217558	4·14	1·4206957
3·37	1·2149127	3·76	1·3244189	4·15	1·4231083
3·38	1·2178757	3·77	1·3271749	4·16	1·4255150
3·39	1·2208299	3·78	1·3297240	4·17	1·4279160
3·40	1·2237754	3·79	1·3323660	4·18	1·4323112
3·41	1·2267122	3·80	1·3350010	4·19	1·4327007
3·42	1·2296405	3·81	1 3376291	4·20	1·4350845
3·43	1·2325605	3·82	1·3402504	4·21	1·4374626
3·44	1·2354714	3·83	1·3428648	4·22	1·4398351
3·45	1·2387420	3·84	1·3454723	4·23	1·4422020
3·46	1·2412685	3·85	1·3480731	4·24	1·4445632
3·47	1·2441545	3·86	1·3506671	4·25	1·4469189
3·48	1·2470322	3·87	1·3532544	4·26	1·4492691
3·49	1·2499017	3·88	1·3558351	4·27	1·4516138
3·50	1·2527629	3·89	1·3584091	4·28	1·4539530
3·51	1·2556160	3·90	1·3609765	4·29	1·4562867
3·52	1·2584609	3·91	1·3635373	4·30	1·4586149
3·53	1·2612978	3·92	1·3660916	4·31	1·4609379
3·54	1·2641266	3·93	1·3686394	4·32	1·4632553
3·55	1·2669475	3·94	1·3711807	4·33	1·4655635
3·56	1·2697605	3·95	1·3737156	4·34	1·4678743
3·57	1·2725655	3·96	1·3726440	4·35	1 4701758
3·58	1·2753627	3·97	1·3787661	4·36	1·4724720
3·59	1·2781521	3·98	1·3812818	4·37	1·4747630
3·60	1·2809338	3·99	1·3837912	4·38	1·4778487
3·61	1·2837077	4·00	1·3862943	4·39	1·4793292
3·62	1·2864740	4·01	1·3887912	4·40	1·4816045
3·63	1·2892326	4·02	1·3912818	4·41	1·4838746
3·64	1·2919836	4·03	1·8937663	4·42	1·4838746
3·65	1·2947271	4·04	1·3962446	4·43	1·4883995
3·66	1·2974631	4·05	1·3987168	4·44	1·4906543
3·67	1·3001916	4·06	1·4011829	4·45	1·4929040
3·68	1·3029127	4·07	1 4036429	4·46	1·4914870
3·69	1 3056264	4·08	1·4060969	4·47	1·4973883
3·70	1·3083328	4·09	1·4085449	4·48	1·4996230
3·71	1·3110318	4·10	1·4109869	4·49	1·5018527
3·72	1·3137236	4·11	1·4134230	4·50	1 5040774
3·73	1·3164082	4·12	1·4158531	4·51	1·5062971

Table of Hyperbolic Logarithms—Continued.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
5·69	1·7387102	5·93	1·7800242	6·17	1·8196988
5·70	1·7404661	5·94	1·7817091	6·18	1·8213182
5·71	1·7422189	5·95	1·7833112	6·19	1·8229351
5·72	1·7439687	5·96	1·7850704	6·20	1·8245103
5·73	1·7457155	5·97	1·7867469	6·21	1·8261608
5·74	1·7474591	5·98	1·7884205	6·22	1·8277639
5·75	1·7491998	5·99	1·7900914	6·23	1·8293763
5·76	1·7509374	6·00	1·7917594	6·24	1·8309801
5·77	1·7526720	6·01	1·7934247	6·25	1·8325814
5·78	1·7544036	6·02	1·7950872	6·26	1·8341801
5·79	1·7561323	6·03	1·7967470	6·27	1·8357763
5·80	1·7578579	6·04	1·7984040	6·28	1·8373699
5·81	1·7595805	6·05	1·8000582	6·29	1·8389610
5·82	1·7613002	6·06	1·8017098	6·30	1·8405496
5·83	1·7630170	6·07	1·8033586	6·31	1·8421356
5·84	1·7647380	6·08	1·8050047	6·32	1·8437191
5·85	1·7664416	6·09	1·8066481	6·33	1·8453002
5·86	1·7681496	6·10	1·8082887	6·34	1·8468787
5·87	1·7698546	6·11	1·8099267	6·35	1·8484547
5·88	1·7715567	6·12	1·8115621	6·36	1·8500283
5·89	1·7732559	6·13	1·8131947	6·37	1·8515994
5·90	1·7749523	6·14	1·8148247	6·38	1·8531680
5·91	1·7766458	6·15	1·8164520	6·39	1·8547342
5·92	1·7783364	6·16	1·8180767	6·40	1·8562979

Table of the Expansion of Air by Heat, that at 32° Fahrenheit being 1·000.

Fah.	Volume.	Fah.	Volume.	Fah.	Volume.
35° ...	1·007	85° ...	1·121	170° ...	1·295
40 ...	1·021	90 ...	1·132	180 ...	1·315
45 ...	1·032	95 ...	1·142	190 ...	1·334
50 ...	1·043	100 ...	1·152	200 ...	1·364
55 ...	1·055	110 ...	1·173	210 ...	1·372
60 ...	1·066	120 ...	1·194	212 ...	1·376
65 ...	1·077	130 ...	1·215	302 ...	1·558
70 ..	1·089	140 ...	1·235	392 ...	1·739
75 .	1·099	150 ...	1·255	482 ...	1·919
80 .	1·110	160 ...	1·275	572 ...	2·098

NOTE.--One hundred parts of pure air by weight contain 75·55 parts of nitrogen, 23·32 parts oxygen, and 1·3 carbonic acid, and watery vapour.

The weight or pressure of the atmosphere equal a column of water 34 feet in height, or a column of mercury 30 inches in height, or 14·7 pounds per square inch at a mean temperature.

The resistance of air increases as the square of the velocity, and the resistance per square foot as the velocity multiplied by ·002288.

Table of Specific Gravities.

Metals.	Weight, water being 1000.	Number of cubic inches in a pound.	Weight of a cubic inch in pounds.
Platina	19500	1·417	·7053
Pure gold	19258	1·435	·6965
Mercury	13560	2·04	·4902
Lead	11352	2·435	·4105
Pure silver	10474	2·638	·3788
Bismuth	9823	2·814	·3552
Copper	8788	3·146	·3178
Brass	7824	3·533	·3036
Iron, cast	7264	3·806	·263
Iron, bar	7700	3·592	·279
Steel	7833	3·530	·2833
Tin	7291	3·790	·2636
Zinc	7190	3·845	·26

Various Bodies.	Weight, water being 1000.	Weight of a cubic foot in pounds.	Number of cubic feet in a ton.
Marble, average	2720	170·0	13
Granite, do.	2651	165·6	13·5
Chalk, British	2781	173·8	12·75
Brick, red, common	2160	135·0	17·5
Brick, fire, Welsh	2408	150·5	14·5
Tallow, average	942	59·0	38·0
Ice, from fresh water	1001	53·0	35·5
Coal, Welsh	1526	95·3	24·7
Coal, Lancashire	1319	82·4	26·0
Coal, Scotch	1300	81·5	27·5
Coal, cannel	1272	79·5	28·0
Coal, Newcastle	1270	79·3	28·2
Coke, dry	755	47·0	47·6

Specific Gravities—Continued.

UIDS.	Weight, water being 1000.	Weight of an imp. gallon in pounds.
Dead Sea . . .	1240	12·4
Mediterranean .	1029	10·3
Irish Channel .	1028	10·2
Baltic	1015	10·2
. . . . .	1010	10·1
. . . . .	991	9·8
. . . . .	940	9·4
. . . . .	923	9·2
. . . . .	922	9·2
. . . . .	919	9·3
. . . . .	915	9·2
. . . . .	837	8·3

Gases, Atmospheric Air being 1000.

gas	1527
. . . . .	1111
ydrogen	972
. . . . .	969
r at 212°	623
. . . . .	470
. . . . .	69

Table of the Weight of Bar Iron.

ROUND.

Diameter in inches.	Length, one foot.		Diameter in inches.	Length, one foot.	
	Weight in pounds.	Weight in pounds.		Weight in pounds.	Weight in pounds.
¼	·164	·0137	3⅛	25·620	2·135
5/16	·256	·0233	3¼	27·709	2·309
⅜	·369	·0307	3⅜	29·881	2·490
7/16	·503	·0420	3½	32·170	2·681
½	·656	·0547	3⅝	34·472	2·873
9/16	·831	·0692	3¾	36·895	3·075
⅝	1·025	·0854	3⅞	39·390	3·283
11/16	1·241	·1034	4 in.	41·984	3·499
¾	1·476	·1230	4⅛	44·637	3·720
13/16	1 732	·1443	4¼	47·385	3·949
⅞	2·011	·1676	4½	53·132	4·428
15/16	2·306	·1921	4¾	59·187	4 932
1 in.	2·624	·2187	5 in.	65·585	5·465
1⅛	3·321	·2767	5¼	72·618	6·051
1¼	4·099	·3146	5½	79 370	6·614
1⅜	4·961	·4134	5¾	86·731	7·227
1½	5 913	·4927	6 in.	94·610	7·884
1⅝	6 928	·5773	6½	110·84	9·237
1¾	8·043	·6702	7 in.	128 68	10
1⅞	9·224	·7686	7½	147 58	1
2 in.	10·496	·8747	8 in.	167 94	1
2⅛	11·846	·9872	8½	189·54	
2¼	13·283	1·107	9 in.	212 53	
2⅜	14·797	1·233	9½	236·75	
2½	15·396	1·366	10 in.	262·34	
2⅝	18·146	1·512	10½	290·47	
2¾	19·842	1 653	11 in.	317·48	2
2⅞	21·684	1·307	11½	346·93	2
	23 653	1·971	12 in.	378·44	31

ENGLISH STANDARD MEASURES.

LINEAL MEASURE.

12 inches	= 1 foot.
3 feet	= 1 yard.
1760 yards, or 5280 feet	= 1 statute mile.
7·92 inches	= 1 link.
100 links, or 22 yards	= 1 chain.
80 chains	= 1 statute mile

SQUARE MEASURE.

144 square inches	= 1 square foot.
9 square feet	= 1 square yard
4840 square yards	= 1 acre.
62·7264 square inches	= 1 square link.
10000 square links	= 1 square chain
10 square chains	= 1 acre.

CUBIC MEASURE.

1728 cubic inches	= 1 cubic foot.
27 cubic feet	= 1 cubic yard.

LIQUID MEASURE.

8·665 cubic inches	= 1 gill.
4 gills	= 1 pint.
2 pints	= 1 quart.
4 quarts, or 277·274 cubic inches	= 1 gallon.

CORN MEASURE.

2 gallons	= 1 peck.
4 pecks, or 2218·192 cubic inches	= 1 bushel.
8 bushels	= 1 quarter.
5 quarters	= 1 load.

AVOIRDUPOIS WEIGHT.

27·34375 troy grains	= 1 drachm.
16 drachms	= 1 ounce.
16 ounces	= 1 pound.
28 pounds	= 1 quarter.
4 quarters, or 112 pounds	= 1 cwt.
20 cwts., or 2240 pounds	= 1 ton.

To compare Degrees of Temperature indicated by different Thermometers.

RULE 1.—Multiply degrees of Centigrade by 9 and divide by 5; or multiply degrees of Reaumur by 9 and divide by 4. Add 32 to the quotient in either case, and the sum is degrees of Fahrenheit.

RULE 2.—From degrees of Fahrenheit subtract 32, multiply the remainder by 5, and divide by 9 for degrees of Centigrade; or multiply by 4 and divide by 9 for degrees of Reaumur.

Tables deduced from Experiments on Iron and Copper Plates for Steam Boilers, by the Franklin Institute, Philadelphia.

Iron boiler plate was found to increase in tenacity as its temperature was raised, until it reached a temperature of 550° above the freezing point, at which point its tenacity began to diminish. The following table exhibits the cohesive strength at different temperatures:—

At	32° to 80°	the tenacity was	= 56,000 lbs., or one-seventh below its maximum.
At	570°	" "	= 66,500 lbs., the maximum.
At	720°	" "	= 55,000 lbs., the same nearly as at 32°.
At	1050°	" "	= 32,000 lbs., nearly one-half of the maximum.
At	1240°	" "	= 22,000 lbs., nearly one-third of the maximum.
At	1317°	" "	= 9,000 lbs., nearly one-seventh of the maximum.

At 3000° iron becomes fluid.

NOTE.—The accidental overheating of a boiler was found to reduce its strength from 65,000 pounds to 45,000 per square inch.

Common Gravity of Fresh Water.

1 cubic inch	=	·03617 pound
12 cubic inches	=	·434 "
1 cubic foot	=	62·5 pounds.
1·8 cubic feet	=	1 cwt.
35·84 cubic feet	=	1 ton.
1 cylindrical inch	=	·02842 pound
12 " inches	=	·341 "
1 " foot	=	49·1 pounds.
2·282 " feet	=	1 cwt.
45·64 " feet	=	1 ton.
1 cubic foot	=	6·25 imp. galls.
1 cylindrical foot	=	5 imp. gallons
11·2 imperial gallons	=	1 cwt.
224 " "	=	1 ton.
1 cubic foot of sea-water	=	64·2 pounds.
34·9 cubic feet of do.	=	1 ton.

Approximate Weights for Practical Purposes.

	Specific gravities.	Weight of a cubic inch in pounds.	Weight of a cylindrical inch in pounds.
Iron, cast	7207	·2608	·2048
Iron, bar	7700	·2785	·2187
Steel	7833	·2833	·2225
Copper	8878	·3211	·2522
Brass, cast	8396	·3037	·2385
Zinc, common	7028	·2542	·1996
Lead	11352	·4106	·3225
Tin, cast	7291	2637	·2071

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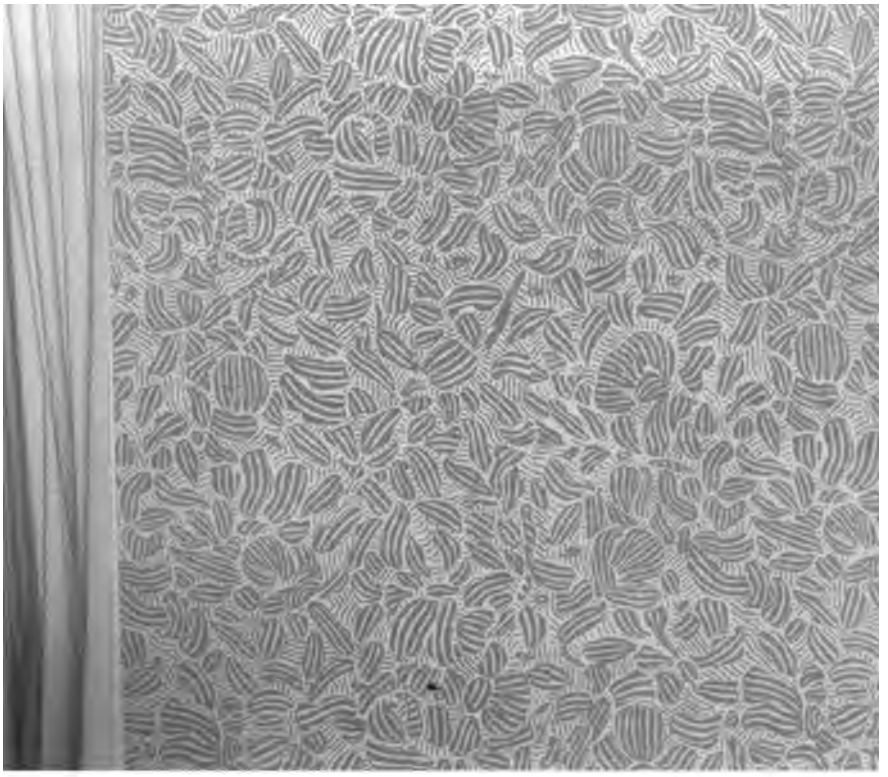

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